How NASA will capture an asteroid p. 22

COMET ISON PHOTO GALLERY p. 50

MARCH 2014

Astronomy®

The world's best-selling astronomy magazine

SPECIAL ISSUE

SPACE ROCKS

What they tell us about the universe

The weird world of Saturn's moon PHOEBE p. 28

Spacecraft travels to Vesta and Ceres p. 44

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Sketch the Messier objects in one night p. 60

Celestron's new Skyris CCD cameras tested p. 66

FROM THE **EDITOR**

BY DAVID J. EICHER

Arizona Science and Astronomy Expo

The second annual Arizona Science and Astronomy Expo (ASAE) took place November 16–17, 2013, in the Tucson Convention Center. Organized by Alan Traino, for years a driving force behind the Northeast Astronomy Forum in New York, the show attracted more than 100 exhibitors, speakers, and hundreds of astronomy enthusiasts.

I was privileged to attend on behalf of *Astronomy* along with our advertising guru Jeff Felbab. We had constant activity at the *Astronomy* booth, right around the corner from our friends at Celestron. It was amazing to see a number of folks I've known since I was a teenager — observers and writers Tom and Jennifer Polakis, deep-sky expert and U.S. Geological Survey geodesist Brent Archinal, dark-sky crusader David Crawford, great astroimager Jason Ware, Scott Roberts of Explore Scientific, and others.

Huge displays from Celestron — where Dave Anderson, Michelle Meskill, Lonnie Wege, and others happily helped customers — and Meade Instruments — with new executives Joe Lupica and Victor Aniceto — featured a number of spectacular (and large) telescopes. Explore Scientific featured Roberts' magnificent tractor-trailer showroom, filled with high-quality optics. Tele Vue had a significant presence too, along with Canon and numerous other imaging companies, all in impressive swing and with many featuring new products.

The talks I heard were amazing. Alex Filippenko of the University of California, Berkeley, detailed what we know about dark energy and the fate of the universe. Later, astronaut Story Musgrave, the only human to have flown on all five space shuttles, delivered a great talk about his life.

With friends Dolores and Rik Hill at ASAE. DAVID J. EICHER

An exploration of spacecraft missions in the solar system, present and future, came from Emily Lakdawalla of The Planetary Society. Following this, I joined several experts on comets for a discussion that was moderated by comet scientist and discoverer Carl Hergenrother of the University of Arizona's Lunar and Planetary Laboratory (LPL). The panel also included Steve Larson and Jim Scotti, both of LPL, and comet discoverer and astronomy popularizer David Levy. It was great fun, and afterward I signed copies of my new book, *COMETS! Visitors from Deep Space*, from Cambridge University Press.

Finally, one of the great folks in the field, Tim Ferris, delivered the keynote address on cosmology, dark matter, the Big Bang, cosmic evolution, quantum weirdness, and the whole rest of that story, enthralling the audience.

I also had fun chatting with Adam Block of the University of Arizona's Mount Lemmon SkyCenter, who begins his monthly column on astroimaging in this issue. Please join me in welcoming him. (Tony Hallas is retiring from the column — still contributing to the magazine but taking a break from the monthly grind. Tony, thanks for the years of great information you delivered.) You can find Block's debut on p. 20.

Yours truly,

David J. Eicher
Editor

Astronomy

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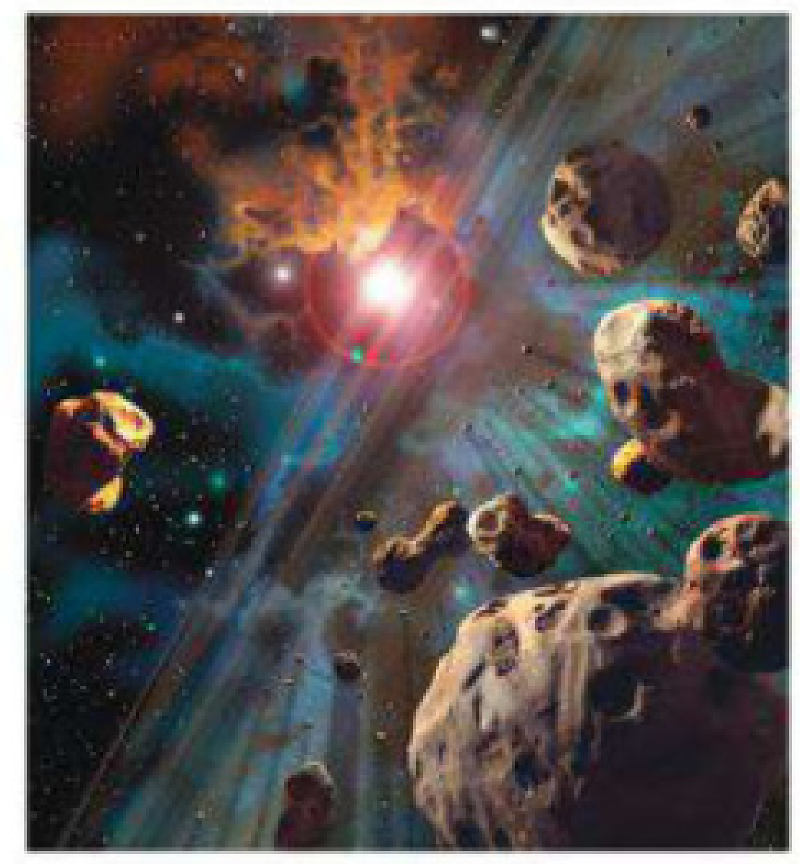


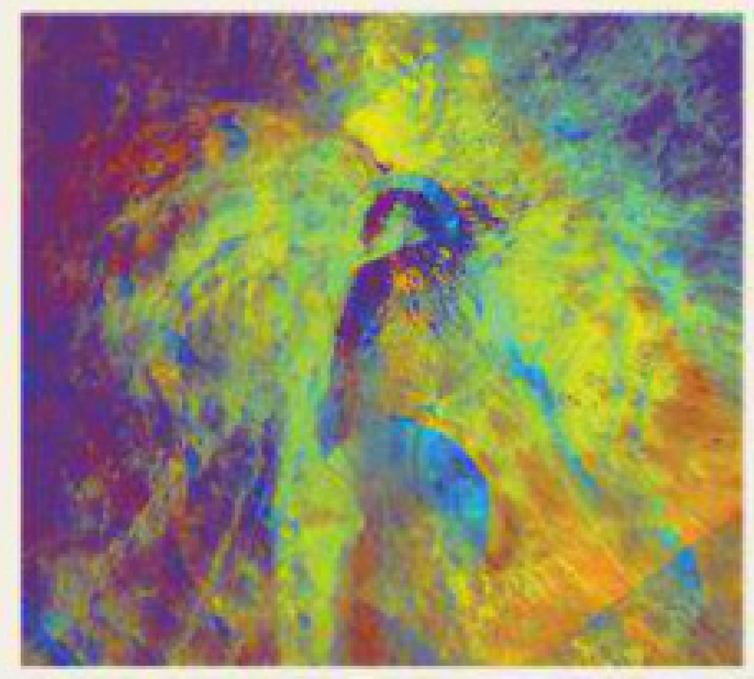
RON MILLER FOR *ASTRONOMY*

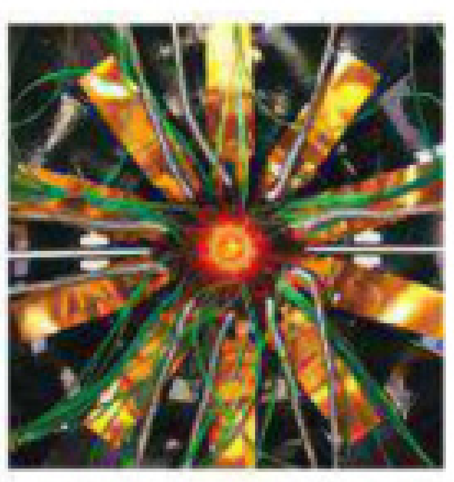
ON THE COVER

From big to small, we've got asteroids covered — from giant Ceres and Vesta to captured Phoebe to a tiny object humans may visit one day.

FEATURES

SPACE ROCKS: What they tell us about the universe





COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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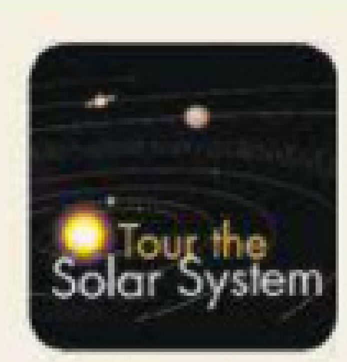

Tour the Solar System
Videos about our planetary neighborhood

StarDome Plus
Map the sky from your location

Comet ISON may have vaporized — but our photo contest hasn't!
Join the National Science Foundation, *Astronomy* magazine, and *Discover* magazine for a big announcement of our Comet ISON Photo Contest winners! The contest features prizes up to $2,500.
Many astroimagers shot great images of the comet (C/2012 S1) from September through November 28. *Astronomy* Editor David J. Eicher will announce and show the competition's winning photos at the 2014 Northeast Astronomy Forum, Saturday, April 12, at Rockland Community College in Suffern, New York.
For more information on NEAF, see: www.rocklandastronomy.com/neaf
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QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

NEXT STEPS
The European Space Agency has chosen the research themes of its next large missions: X-ray astronomy (launching in 2028) and gravitational waves (2034).

NEAREST STAR
Astronomers with the Hubble Space Telescope released the scope's newest image of the nearest star to the Sun, Proxima Centauri, on November 1.

X-RAY RESULT
Astronomers have discovered that a reverse shock wave moving inward at Mach 1,000 heats Tycho's supernova remnant and causes it to glow in X-rays.

SNAPSHOT

Harlow Shapley and globular clusters

Deciphering the distance scale of the cosmos.

Last autumn, I delivered a talk about great astronomical discoveries — and comets — at Harvard College Observatory in Cambridge, Massachusetts. As I spoke at the podium touching on the contributions to astronomy made by Harlow Shapley, among others, it struck me that Shapley himself had lectured right from where I was standing.

Unlike me, however, Harlow Shapley made towering contributions to astronomy. One of the biggest came in the decade of World War I, when he measured the positions and distances of the 93 globular star clusters then known in our galaxy. Shapley discovered that these clusters are distributed in a spherical cloud centered on Sagittarius.

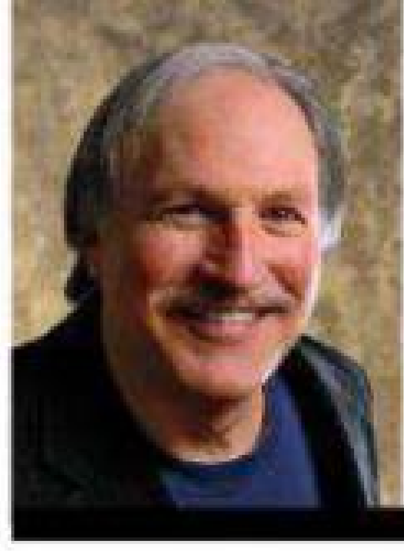
Shapley deduced that the central point of this cloud was the center of the Milky Way, and thus a modern understanding of our galaxy was born. — **David J. Eicher**

The Hercules Cluster (M13) imaged with the Hubble Space Telescope. NASA/ESA/HUBBLE HERITAGE TEAM (STScI/AURA)

© AEI/MM/EXOZET; GRAVITATIONAL WAVE SIMULATION: NASA/C. HENZE (NEXT STEPS); NASA/ESA (NEAREST STAR); X-RAY: NASA/CXC/RUTGERS/K. ERIKSEN, ET AL.; OPTICAL: DSS (STARRY BACKGROUND) (X-RAY RESULT)

Spiral or elliptical?

Deep in the southern sky lurks an unassuming galaxy with a pedestrian name: PGC 10922. But the Hubble Space Telescope can find beauty in strange places. This lenticular galaxy shows characteristics of both spirals (note the delicate spiral structure near the center) and ellipticals (the near total lack of interstellar gas). The galaxy does harbor a lot of dust, however, which delineates the arms and spreads into the outer halo. PGC 10922 lies roughly 225 million light-years from Earth in the constellation Octans. Despite its vast distance, scads of more distant galaxies pepper the field.
ESA/HUBBLE & NASA; JUDY SCHMIDT



STRANGE**UNIVERSE**

BY BOB BERMAN

Equinox energy and emptiness

Our vast universe possesses all the energy it's ever going to have.

This month brings the equinox. On the 20th at 12:57 P.M. EDT, the Sun hovers over the equator in South America. There's approximate day/night equality everywhere. In Woodstock, New York, a 20-minute drive from my home, the equinox is associated with the word *energy*, as in: "Earth's energy is now balanced."

There really is a kind of balance on the equinox. The symmetry comes from Earth's terminator — the line separating day from night — crossing both poles on the 20th. (Thanks to refraction caused by our atmosphere, they both bask in full sunlight that day, with no night in either place).

On the equinox alone, each spot on our spinning world meets the terminator perpendicularly. The result: Everyone sees a due-east sunrise and a due-west sunset. Moreover, it's the sole midday occasion when the Sun's distance from the overhead point equals your latitude. Say you live in Los Angeles or Sydney, whose latitudes are 34°; that day, the Sun hovers 34° from straight up. At the equator, latitude 0°, the Sun hits the zenith. Cool stuff.

But back to that Woodstock energy business. Although more an expensive artsy tourist mecca than a hippie hangout, locals sometimes use New Age vernacular and say things like, "Everything is energy."

Oddly enough, it's true. Everything is energy.

Physicists used to believe in many types of energy. Chemical, electrical, radiant — it was a long list. Nowadays, science says all the unfolding activity we see is kinetic energy, the energy of motion. Consider heat: Is this a distinct energy variety? It certainly has power. Heat raises gas pressure that can drive pistons. But "heat" is just our word for atoms in motion. A hot object merely has faster-moving particles. Once again, it's all kinetic energy.

Whether the universe is finite or infinite, it possesses all the energy it's ever going to have. It never decreases. This seems counterintuitive only because energy appears to get depleted. Our car's gas gives the vehicle power, and eventually the fuel's gone. In reality, the tires warm the road a bit, some heat goes out the tailpipe or wafts from the hot engine, and it all warms the atmosphere. None is gone.

NOWADAYS, SCIENCE SAYS ALL THE UNFOLDING ACTIVITY WE SEE IS KINETIC ENERGY.

Moreover, there seems to exist an unimaginably vast underlying energy field, sometimes called vacuum energy or zero-point energy, that pervades the cosmos. Ever since physicists first noticed the Casimir effect in 1948, whereby two suspended metal plates dangling close together are mysteriously pushed into each other by some outside force, evidence has accumulated that makes this universal energy matrix seem more likely than not.

Finally, even inert solids like rocks are actually immense energy clumps because matter and energy are equivalent. A single pencil eraser weighing 1 gram contains the same energy released in the larger of the two atomic bombs that fell on Japan in 1945. Thus, energy is ubiquitous.

All this energy unfolds spontaneously. Orbiting planets, mutating thunderstorm clouds, and scurrying mice all effortlessly exhibit this endless power. There are no separate events. Our minds alone, trying to understand what's going on, create the boundaries between activities. It's all actually interconnected.

People generally see themselves as sources of energy separate from the universe. But Arthur Schopenhauer, the 19th-century philosopher who deeply influenced Albert Einstein, liked to say, "A man can do what he wills, but he cannot will what he wills." He didn't believe in discrete personal power and insisted our lives unfold spontaneously.

Physics supports this. Indeed, Einstein — expressing an outlook at odds with Western sensibilities — repeatedly averred that free will is an illusion. Most readers would probably dispute Einstein and claim they do have free will. But maybe they can't help thinking and saying that.

We also can't help dividing the cosmos into various theaters of action. Pockets of separate energy seem logical because our solar system is so isolated. How lonely are we? Make a scale model with Earth as an invisible dust mote. The Sun — only 1 inch (2.5 centimeters) away — would be the period at the end of this sentence. The nearest star is another dot 4.3 miles (6.9 kilometers) distant. Breathtaking emptiness.

On this scale, the diameter of our galaxy would extend halfway to the Moon. Thus, even when our planet is too tiny to see, the model itself assumes astronomical proportions. A galaxy is like billions of sand grains, each separated by miles from its nearest neighbor.

Astronomy is accustomed to such huge separations. Nonetheless, cosmic rays from the rest of the universe penetrate our bodies, cause genetic mutations, and keep changing Earth's biosphere. Our biological evolution began in the far corners of the cosmos. All energies are interconnected.

They love this kind of talk in Woodstock — especially on the equinox.

Contact me about my strange universe by visiting **http://skymanbob.com.**

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Sarah Scoles**

Cold as space — Supernova hot

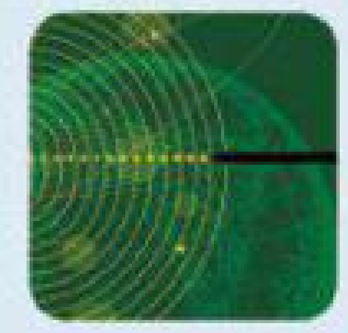
Failing science

After 16 days of federal shutdown — when many scientists couldn't work — facilities reopened. Office plants had died and E.T. had called, to no answer.

Penny pinchers

NASA's Curiosity rover returns its highest-res images — pictures not of Mars but of a penny it brought along. Yay, science? Lincoln looks great, as usual.

Alternate universe



Astronomer Kristine Larsen maps the solar system of J. R. R. Tolkien's "Middle-earth" using textual clues. Next, she'll calculate the orbit of the *Game of Thrones'* red comet.

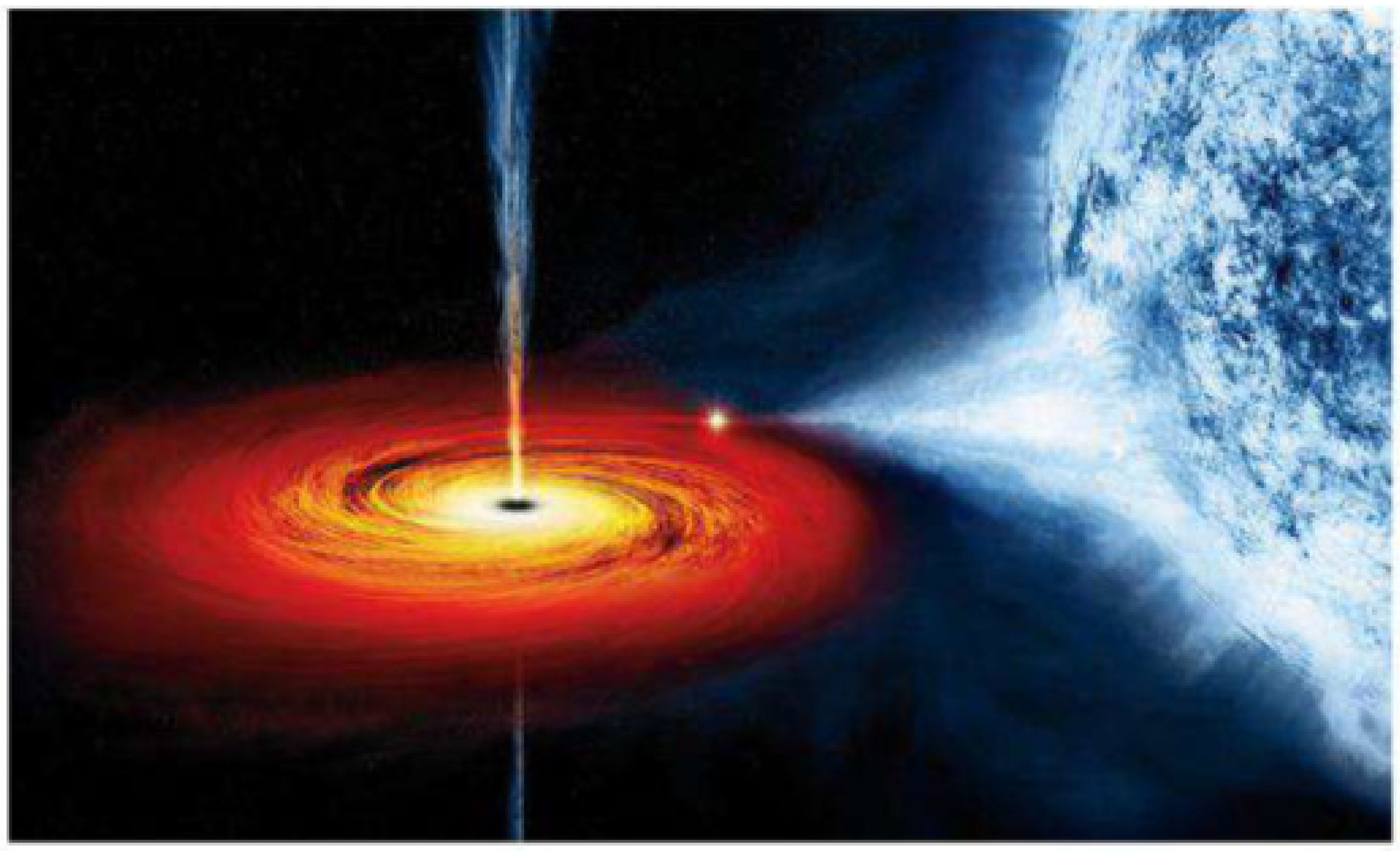
Rogue planet

Astronomers discover a young planet floating free in space — no star attached. The angsty planet said it had to run away because its parent solar system just didn't understand.

NASA (FAILING SCIENCE); NASA/JPL-CALTECH/MSSS/PLANETARY SCIENCE INSTITUTE (PENNY PINCHERS); THINKSTOCK/STOCKBYTE (ALTERNATE UNIVERSE); N. METCALFE/PAN-STARRS 1 SCIENCE CONSORTIUM (ROGUE PLANET)

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

SOLAR HEATING? The Sun's changing activity can account for at most 10 percent of the 20th century's global warming, scientists announced in the November 8 issue of *Environmental Research Letters*.



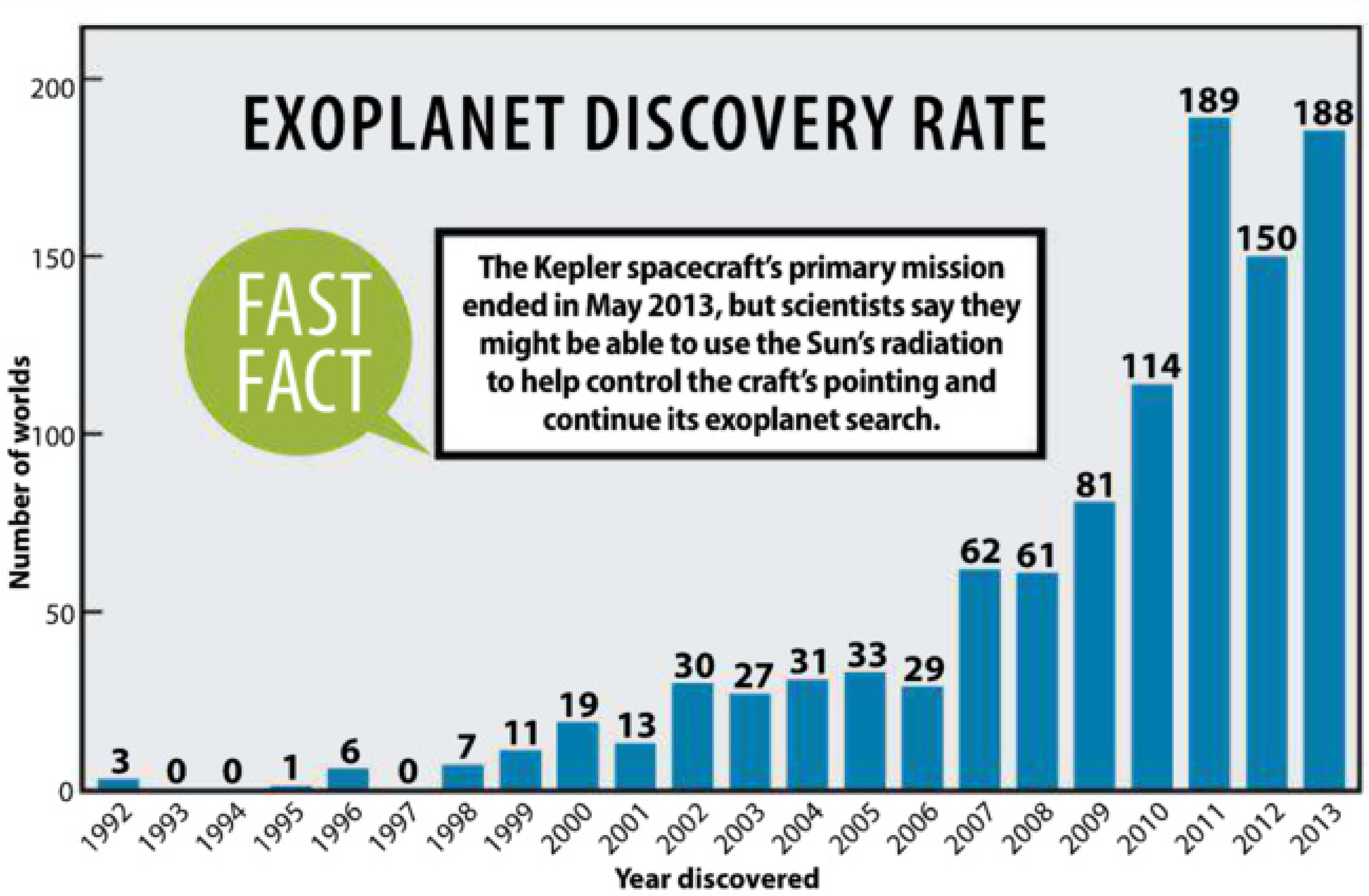
HEAVY METAL. Astronomers have discovered that jets resembling those emerging from this illustrated black hole contain atoms like nickel and iron, heavy elements that could fuel star formation and affect the fates of host galaxies. NASA/CXC/M. WEISS

BLACK HOLE JETS FULL OF METAL

The jets of typical supermassive black holes contain iron and nickel — "heavy" atoms as far as the universe is concerned — according to observations from the XMM-Newton space telescope and the Australia Telescope Compact Array. The results appeared online November 13 in *Nature*.

Astronomers have long known that the jets contain electrons, but these particles are 100,000 times less massive than iron and thus have much less energy than the comparatively huge atoms. The discovery of heavy elements, however, is not just important in terms of the jets' power. These beams of particles and radiation also send potential star-forming material back into the galaxy at large, so their contents affect the galaxy's evolution as well as the characters of individual stars. "Jets from supermassive black holes help determine a galaxy's fate," says Tasso Tzioumis of Australia's national science agency and a member of the research team. "So we want to understand better the impact jets have on their environment."

The discovery also has gravitas because it illuminates the engine behind the jets, whose origin is a subject of current debate. If the black hole itself fuels the jets, they are likely to contain only radiation. If, however, the material that is falling toward the black hole energizes them, it makes sense that this material, which would contain heavy atoms, would make its way into the jet itself. — **Sarah Scoles**



PLANET HAUL. Scientists found the first candidate worlds orbiting other stars in 1992. Since then, they've discovered more than 1,000 of these exoplanets. And, as expected, improved technology helped the discovery rate increase dramatically. (For reference, the Kepler spacecraft launched in 2009, and the researchers with the mission released their first results in 2010.) The data shown here come from The Extrasolar Planets Encyclopaedia (http://exoplanet.eu) and were up-to-date as of December 20. *ASTRONOMY*: LIZ KRUESI AND ROEN KELLY

BRIEFCASE

MARS: MORE COMPLICATED

New observations suggest that Mars harbors feldspar-rich rocks. These compounds are similar to granite commonly seen on Earth within tectonically active regions but were unexpected on the Red Planet. While the Curiosity rover found evidence of such materials within Gale Crater in early 2013, new Mars Reconnaissance Orbiter data published online in two November 17 *Nature Geoscience* papers suggest feldspar-rich rocks might be more widespread across the planet's surface.

MISSING MINERALS?

According to a *Nature* study published online November 6, the asteroid Vesta's mantle doesn't have the distribution of olivine scientists had expected. This mineral is a major component in mantles of terrestrial planets and protoplanets, but Dawn spacecraft data indicate there is none at Vesta's deep south-pole basins, which show exposed lower crust and mantle. Instead, olivine lies in the surface material in the body's northern hemisphere.

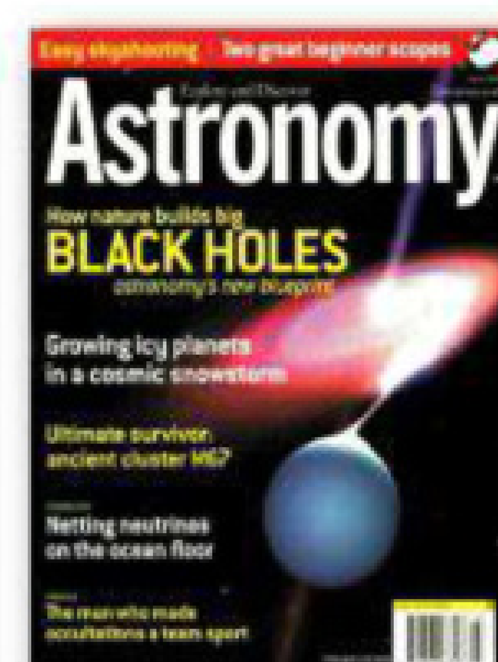
COLD AND BROWN

Astronomers have confirmed two fast-moving brown dwarfs, objects more massive than gas giant planets but not massive enough to become stars, originally discovered in infrared data from the Wide-field Infrared Survey Explorer. Each of the newly found bodies is more than 10 billion years old and glows between 480° and 1110° Fahrenheit (250° and 600° Celsius). The scientists' discoveries appeared online November 19 in *Monthly Notices of the Royal Astronomical Society*. — **Liz Kruesi**

25 years ago in *Astronomy*

In the March 1989 issue of *Astronomy*, James Charles LoPresto wrote "Looking inside the Sun," describing what our star's interior could teach us, a field of study known as helioseismology. "Is the Sun's core rotating? How fast? Do we know its central temperature? … Is the solar diameter contracting?" the article asked.

By studying the Sun's shakes and quakes for the 25 years hence, astronomers now know those questions' answers are "yes," "approximately once every 6.5 days," "26 million degrees Fahrenheit (15 million degrees Celsius)," and "nope."



10 years ago in *Astronomy*

In the March 2004 issue of *Astronomy*, Steve Nadis wrote "Black holes in the middle" about hypothetical intermediate-mass black holes (IMBHs) and whether they are the building blocks that turn into the black holes lurking at galactic centers.

Roeland van der Marel of the Space Telescope Science Institute in Baltimore expressed hope that scientists would soon find IMBHs. "Observational techniques are just reaching the point where we can get some answers," he said. He was right: Astronomers confirmed the first IMBH that November. — **S. S.**

METEORITE MATERIALS. The remnants of the asteroid that exploded over Chelyabinsk, Russia, are LL chondrites, the most common type of meteorite, scientists announced November 29 in *Science*.

Scientists detect extraterrestrial neutrinos

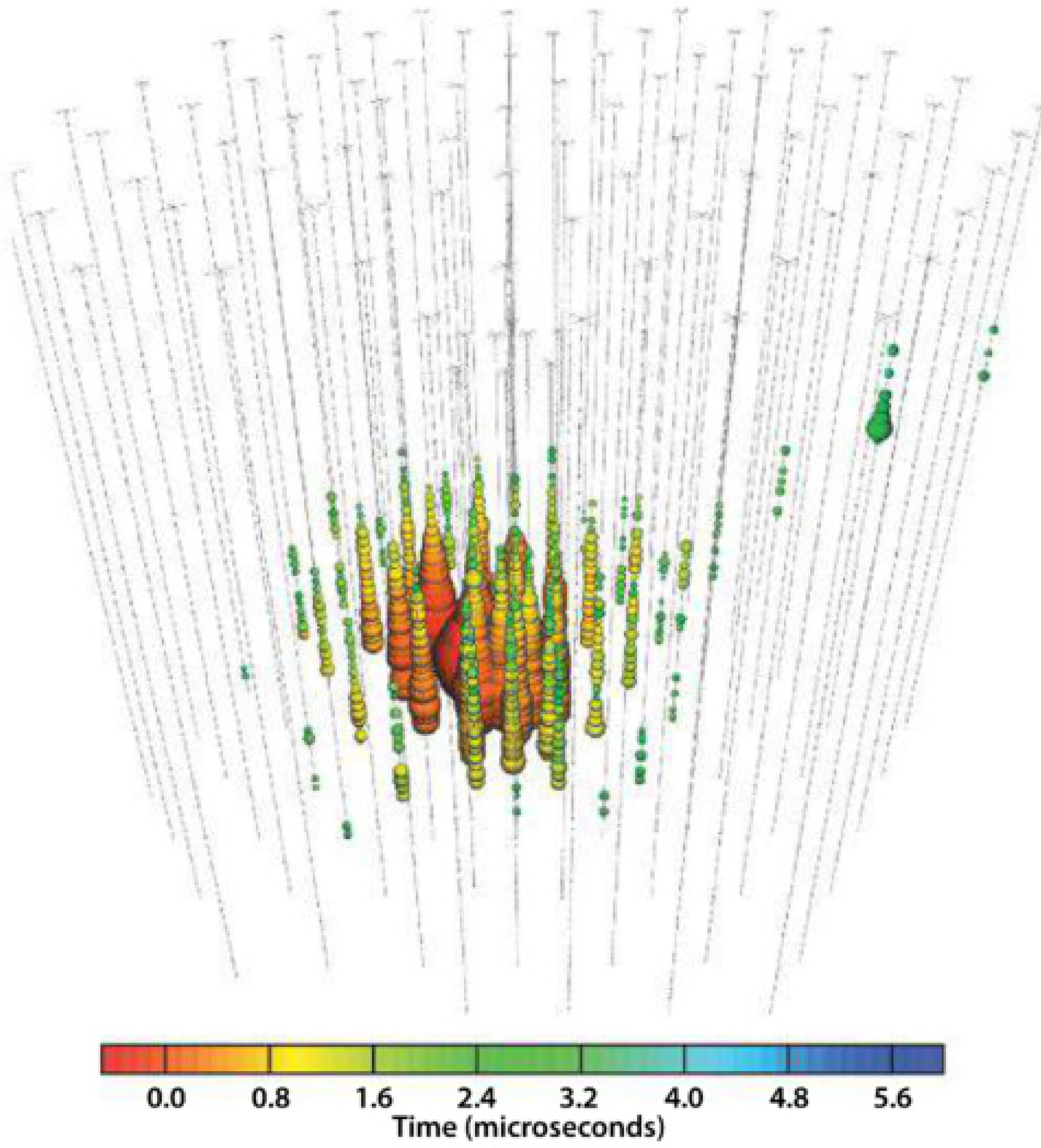
Buried deep in the pristine Antarctic ice lie 5,160 basketball-sized detectors that look for flashes of blue light. This radiation signals that a high-energy particle has interacted with an atom of the ice and given off some energy in the process. Scientists built the underground cubic kilometer IceCube detector to find a specific type of particle called a neutrino. This particle has no electric charge, is nearly massless, and interacts extremely weakly with matter. (In fact, billions of them are zooming through you as you read this story.)

Astronomers have detected neutrinos from the Sun and from Supernova 1987A when a massive star exploded. Now, the IceCube team reports in the November 22 issue of *Science* that it has found 28 high-energy neutrinos during a two-year all-sky search. The newly discovered particles have energies at least a million times that of the SN 1987A neutrinos.

At most, 11 of the 28 detected signals could result from background events or atmospheric neutrinos — those created as high-energy particles called cosmic rays collide with atoms and molecules in Earth's atmosphere and create secondary particles. However, the researchers say the neutrinos don't have the characteristics of atmospheric ones.

They looked in the data for evidence of multiple neutrinos originating from a specific location on the sky or arriving at a similar time but were unable to trace the 28 neutrinos to specific sources. Most of the detected signals correspond to locations on the Southern Hemisphere sky.

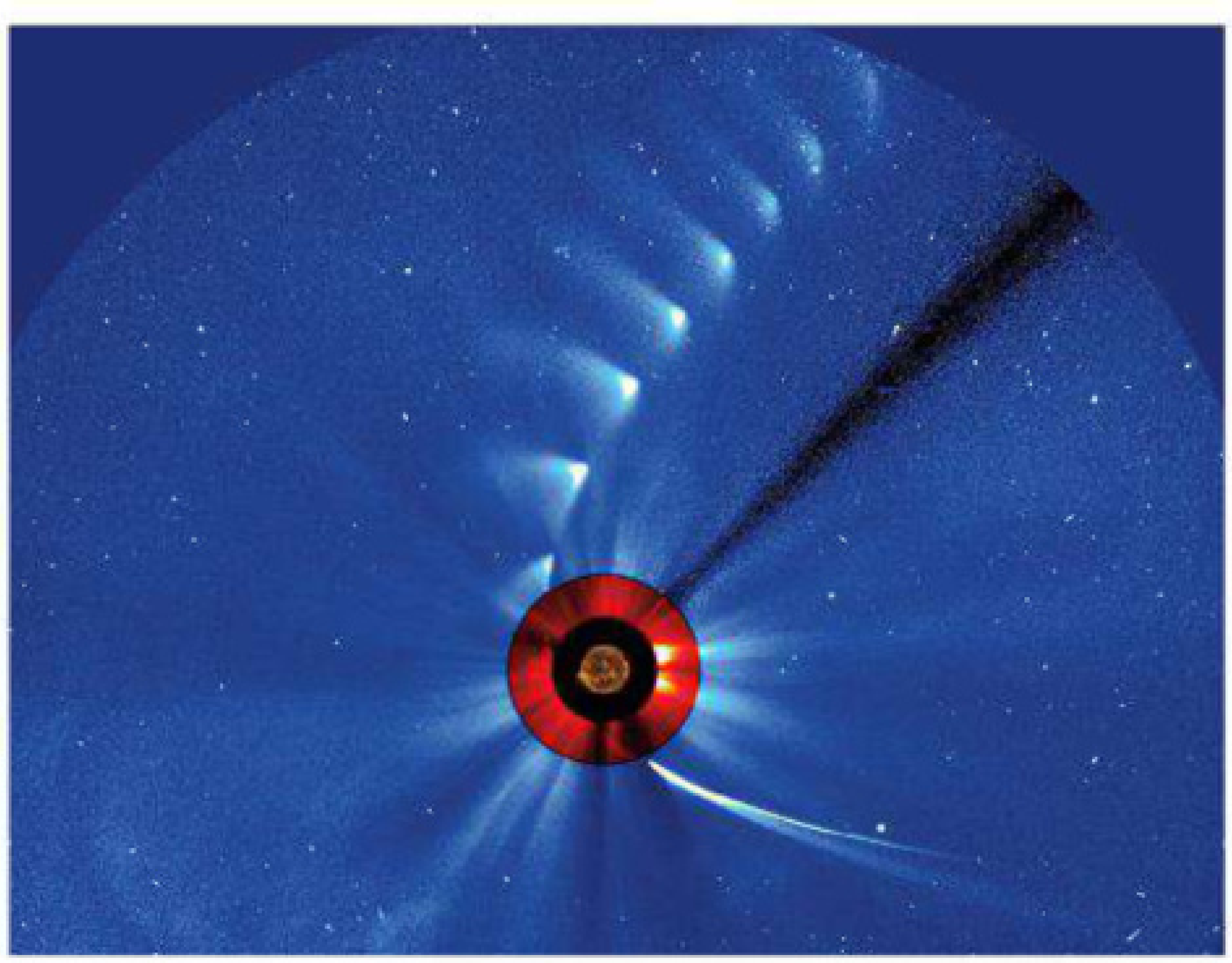
Scientists can calculate the energies of the incoming neutrinos from the light the detectors register. The 28 particles discussed in the *Science* study had energies ranging from 30 trillion electron volts (TeV) to 1,141 TeV; visible light has energy between 1.5 and 3 electron volts. The data also include the two highest-energy neutrinos ever observed. — **L. K.**



PARTICLE PASS. Shortly after a low-mass, neutral-charged, weakly interacting neutrino entered the IceCube detector, it interacted with an ice atom to produce secondary particles and light. This diagram shows the third most energetic neutrino ever detected. The size of the colored spots refers to how much light was seen by each detector; the color corresponds to how long after the initial detection the other instruments observed radiation. ICECUBE COLLABORATION

22% The amount of Sun-like stars that harbor Earth-sized planets in those stars' habitable zones, according to a November 26 *Proceedings of the National Academy of Sciences of the United States of America* study.

ISON fails to survive Sun encounter



ESA/NASA/SOHO/SDO/GSFC

BROKEN UP. The naysayers who postulated the demise of Comet ISON (C/2012 S1) as it made its closest approach to the Sun smugly found themselves saying, "I told you so," November 28. The Sun's intense heat and powerful tidal forces, in combination with ISON's delicate makeup, caused the comet's nucleus to break up as it passed within 730,000 miles (1.16 million kilometers) of the Sun's surface. As this time-lapse image from the Solar and Heliospheric Observatory shows, Comet ISON was brilliant as it headed toward the Sun (bottom right) but reappeared tiny and growing gradually fainter (top right). (The image of the Sun at the center is from the Solar Dynamics Observatory.) Most scientists agree that the visible remnants are small pieces of rubble. — **Karri Ferron**

QUICK TAKES

VIRTUAL REALITY
The Harvard-Smithsonian Center for Astrophysics announced November 15 that a realistic 3-D model of supernova remnant Cassiopeia A will be exhibited at the Smithsonian Institution.

X-RAY EXPECTATIONS
The Chandra X-ray Observatory and the Very Large Array detected a jet of fast-moving particles emerging from the Milky Way's supermassive black hole, the first finding of this suspected feature, NASA announced November 20.

WORK SQUARED
The Square Kilometre Array will be the largest, most sensitive telescope the world has ever seen. It began its next stage of development, in which final design plans will be made, November 5.

LONG-LIVED
Jupiter's Great Red Spot has persisted hundreds of years longer than expected. New models, presented November 25 at the American Physical Society's Division of Fluid Dynamics conference, show that as the vortex loses energy, it sucks more in vertically and radially.

MARTIAN MAKEOVER
As asteroids pass by Mars, the planet's gravity shakes them up, "refreshing" their surfaces by shifting new grains to the top, according to a finding that has been accepted for publication in *Icarus*.

SPACE LIGHTHOUSES
The Low-Frequency Array for Radio Astronomy, which will sweep the sky for transient radio sources, detected two new pulsars during its test runs. Thijs Coenen presented this taste of what's to come November 20 as his Ph.D. dissertation.

MIRROR, MIRROR
The future James Webb Space Telescope, Hubble's would-be successor, now has a spine: The "backplane support structure" of its mirror passed its final tests, NASA announced November 19.

RED GREENHOUSE
Mars was warm enough to host liquid water because its early atmosphere contained the extra greenhouse gas molecular hydrogen, astronomers announced online November 24 in *Nature Geoscience*. — **S. S.**

SECRET**SKY**

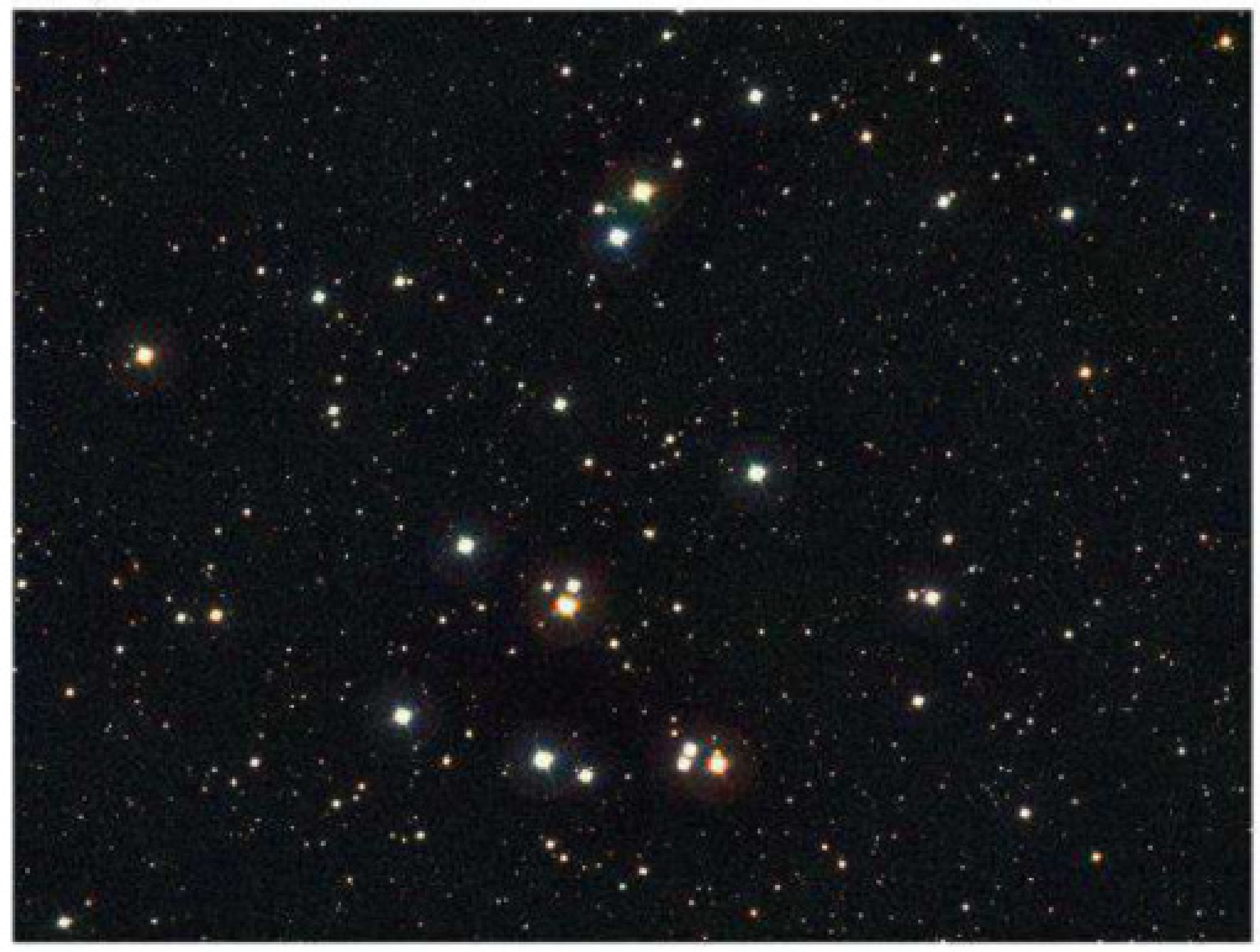
BY STEPHEN JAMES O'MEARA

A pile of corpses

This spring, investigate the ghostly members of the Beehive Cluster.

If you're away from city lights this March, face south after twilight ends and look about halfway up the sky for the Beehive Cluster (M44) in Cancer the Crab. To the unaided eye, M44 appears as a pale patch of ghostly light. It lies roughly midway between Regulus (the Alpha [α] star of Leo the Lion) and Pollux, the southeasternmost "Twin" star in Gemini. It looks as if someone snatched a section of Milky Way and placed it in that stellar desert to breathe life into the area.

M44 is indeed one of the brightest naked-eye open star clusters. It lies only 600 light-years from Earth and has the distinction of outshining all but one star within its constellation's boundaries. As with the Milky Way, it appears misty to the unaided eye because most of the suns that make it up are too dim for viewing without optical aid; most of them also lie too close together for the eye to resolve individually.



Don't be fooled by M44's brightness. Its diameter of 70' means that it covers five times as much area as the Full Moon. 2MASS

Raise binoculars to M44, however, and the haze will splinter into a collection of some 80 suns brighter than magnitude 10. Remove the binoculars from your eyes, and the cluster will dissolve again into a breath of light — and therein lies a story.

Zombie stars

Classically, the naked-eye view of M44 is known as the Praesepe, the Latin word for "manger," and the origin of the Italian *presepio*, meaning "nativity scene." In this view, M44's soft glow is the bed of hay in Christ's crib, while the nearby stars Gamma (γ) and Delta (δ) Cancri — magnitudes 4.7 and 3.9, respectively — are the two guardian *aselli*, or donkeys: Asellus Borealis and Asellus Australis, respectively.

In ancient China, M44 was Tseih She Ke, the "exhalation of piled-up corpses" — apparently the last gasps of flood victims or vapors from prisoners tossed into trenches en masse after execution. When I visualized these gruesome scenes while looking at the cluster with unaided eyes under a dark sky, I could see these "bodies in the mist." With a long, dedicated effort, I resolved a dozen faint stars within the milky confines of the cluster. Indeed, M44 contains 15 stars that shine between magnitude 6.3 and 7.5. Many lie within a north-south "trench" of milkiness that forms the cluster's elongated naked-eye major axis.

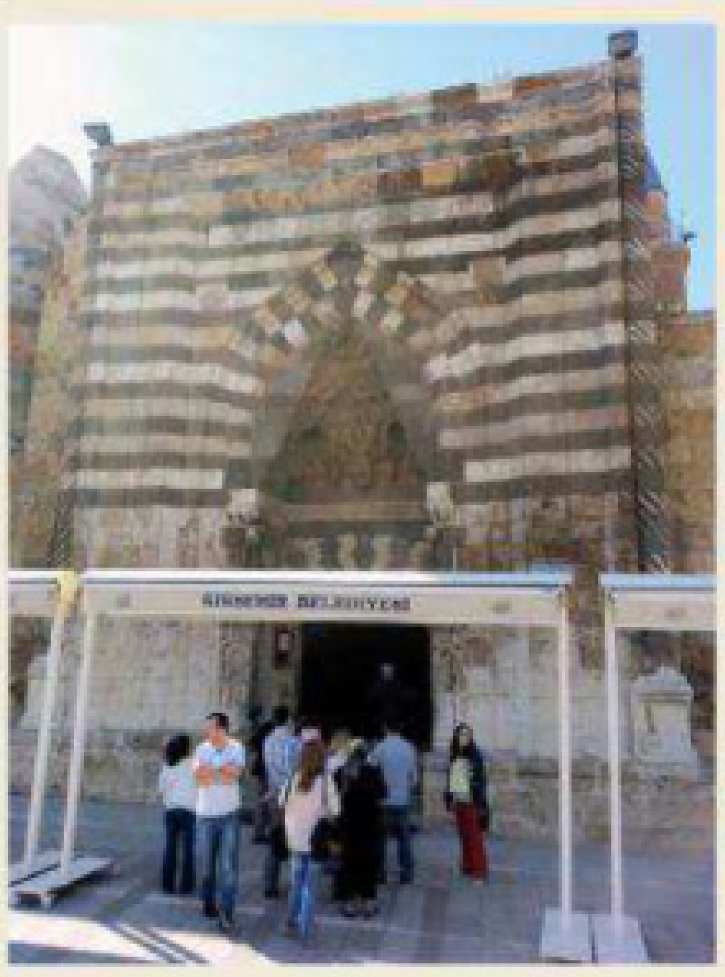
Land of the living dead

The Chinese saw other spectral forms in the region around the Praesepe. They interpreted the trapezoidal asterism of 4th- and 5th-magnitude stars surrounding the cluster — Delta, Gamma, Theta (θ), and Eta (η) — as Gui, meaning "disembodied spirits" or ghosts. Together, M44 and its four attendant stars were seen as another asterism in the lunar mansion Yugui (meaning "carting ghosts"), which was thought to "preside over executions and other dire fates," according to *The Book of Changes: A Bronze Age Document*. In this view, M44 would be a heap of corpses carted through the land of the living dead.

Finally, in a less sinister fashion, the late British astronomy popularizer Patrick Moore noted in his *Cambridge Guide to the Stars and Planets* (Cambridge University Press, 1997) that the modern-day pattern of Cancer "resembles a very dim and ghostly Orion." The pattern is formed by Beta (β), Alpha, Delta, Iota (ι), and Chi (χ) Cancri.

Send your interpretation of the Beehive Cluster to me at sjomeara31@gmail.com.

FROM OUR INBOX



Astronomy in the Anatolia

I am a Turkish physics student, and I would like to introduce *Astronomy* readers to the Cacabey Astronomy Madrasa — *madrasa* is the Arabic word for an educational institution — an astronomy teaching center built in 1272 in Kirsehir, a city in the middle of the Anatolia territory in Turkey.

The dome of the building is open at the top. On the floor beneath the dome is a pool. In the madrasa's early days, people observed the night sky by looking at celestial reflections in this pool. The Cacabey Madrasa is a symbol of the importance people placed on science in the Anatolia of the 1200s. Seljuk scientists of the era observed from many Anatolian buildings like this one. This region and its medieval centers of science are waiting for people in the new millennium.

— **Ahmet Hakan Ergun,** Ankara, Turkey

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

ASTRONEWS **GRASS-ROOTS.** Asteroid mining company Planetary Resources and NASA will crowdsource asteroid detection, they announced November 20.

Three space telescopes witness unprecedented gamma-ray burst

Some 3.8 billion years ago, a massive star died, and light from the event reached Earth on April 27. As the star collapsed into a black hole, jets pummeled through the star's layers, eventually slamming into the space outside. The jets' collisions with stellar innards and, later, with the interstellar medium produced gamma rays — the most energetic form of radiation. The radiation was 500,000 times as powerful as visible light when the jet hit the star's layers, but it was 500,000,000 times as powerful when it collided with the star's surroundings.

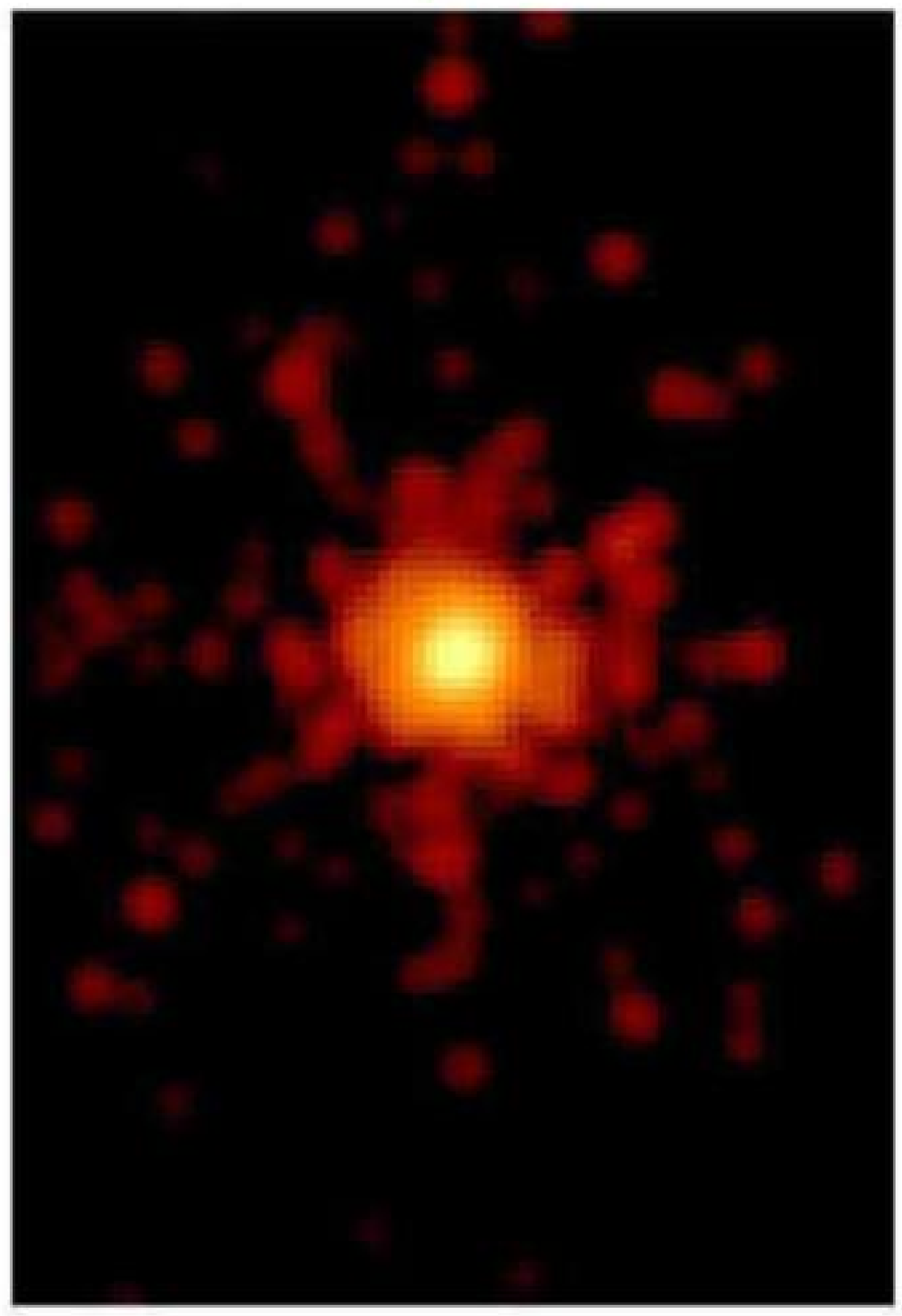
Gamma-ray bursts (GRBs) always happen when huge stars are crushed by their own gravity. But GRB 130427A was special: It was one of the most powerful astronomers have seen and has challenged ideas about how GRBs work.

NASA's Fermi Gamma-ray Space Telescope first saw the burst just before 4 A.M. EDT. Shortly thereafter, the agency's Swift Gamma-ray Burst Mission detected the same radiation and sent the GRB's location to telescopes on the ground so they could record the event in visible light.

From Earth, the optical telescopes saw a magnitude 7 flash — the second-brightest "afterglow" ever recorded. And just as that brightness peaked, Fermi saw a corresponding peak in gamma rays. "We thought the visible light for these flashes came from internal shocks, but this burst shows that it must come from the external shock, which produces the most energetic gamma-rays," says Sylvia Zhu of the University of Maryland in College Park.

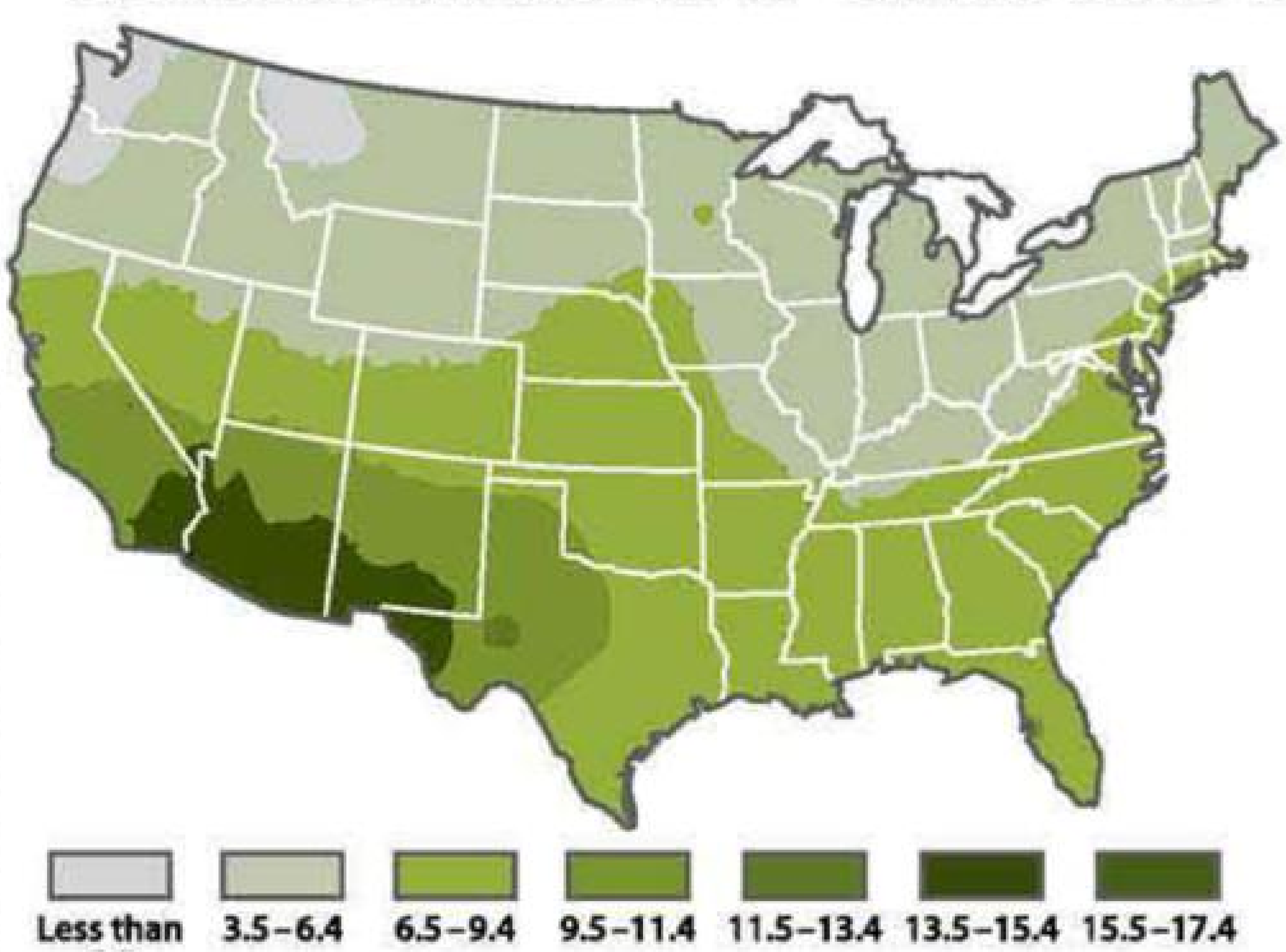
A day later, the Nuclear Spectroscopic Telescope Array observed an X-ray afterglow, the first such high-energy radiation detected and an unexpected finding.

"We expect to see an event like this only once or twice a century, so we're fortunate it happened when we had the appropriate collection of sensitive space telescopes with complementary capabilities available to see it," says Paul Hertz, director of NASA's Astrophysics Division in Washington, D.C. Given the GRB's anomalous nature and the multitude of data, astronomers will be studying this burst for some time to come. Initial results appeared online November 21 in *Science Express*. — **S. S.**



BIG BURST. A gamma-ray burst (GRB) that reached Earth on April 27, 2013, was one of the most powerful ever seen. Three space-based telescopes (including NASA's Swift, whose data is pictured) and a network of ground-based observatories watched the event. GRBs occur when massive stars collapse into black holes. NASA/SWIFT/STEFAN IMMLER

AVERAGE NUMBER OF CLEAR DAYS IN MARCH



ASTRONOMY: MICHAEL E. BAKICH AND ROEN KELLY, AFTER NOAA

FAST FACT

March is the month most amateur astronomers enjoy the Messier marathon (see p. 60).

ASTRO**CONFIDENTIAL** BY KARRI FERRON

WHAT ARE WE LEARNING ABOUT THE COLDEST BROWN DWARFS?

Trent J. **Dupuy** Hubble postdoctoral fellow at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts

Nature has no problem making "stars" that cannot support themselves against contraction under their own gravity. These are called brown dwarfs, which can have up to about 8 percent of the Sun's mass but still have core temperatures too low to ignite the nuclear fusion of hydrogen. As a consequence, brown dwarfs cool dramatically over their lifetimes, falling to temperatures that are otherwise only seen among planets.

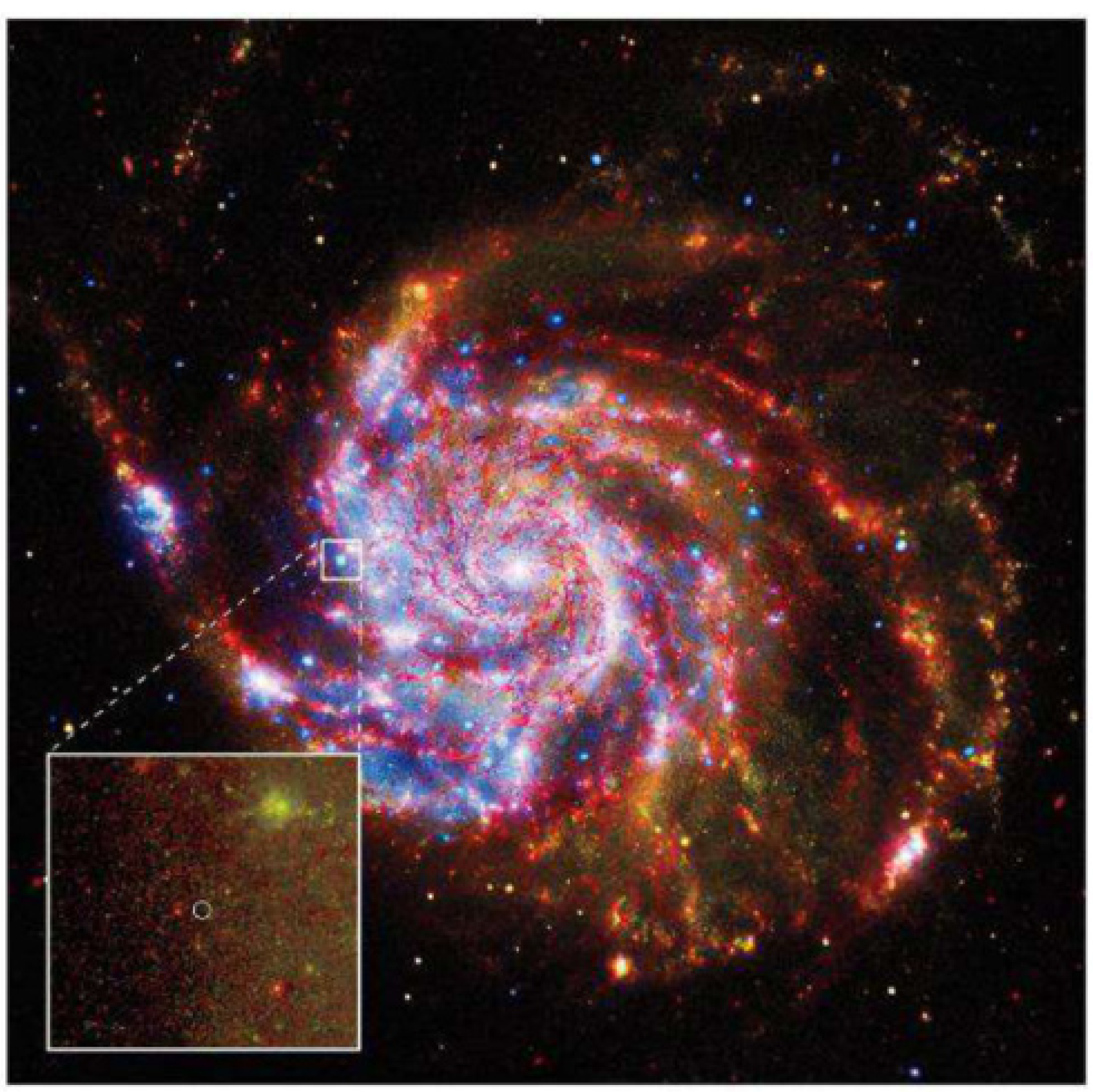
Astronomers are always looking for colder brown dwarfs than the ones we already know of in order to improve our understanding of atmospheric physics at planetary temperatures. Often, however, the very models we'd like to test are the only means we have of readily estimating temperatures for new discoveries. Two years ago, astronomers announced a new class of cold brown dwarfs found in the most sensitive mid-infrared all-sky atlas ever made, from NASA's Wide-field Infrared Survey Explorer (WISE). Initial estimates suggested that the coldest of these could be only 300 kelvins (80° Fahrenheit) at their surface. Such low temperatures implied these objects could have as little as three times Jupiter's mass.

To accurately gauge a brown dwarf's temperature, however, we must measure its distance directly via parallax and determine if it is cooler, and thus fainter, and nearby or warmer, brighter, and more distant. Recently, astronomers obtained the first parallaxes for the new WISE discoveries, revealing that the brown dwarfs are more distant and warmer than expected, though still the coldest brown dwarfs known with masses six to 20 times that of Jupiter. Perhaps most interestingly, many of the new discoveries seem to have indistinguishable temperatures despite having substantial variations in spectral signatures. This diversity had initially been ascribed largely to underlying temperature differences, but it now appears that other properties such as convective mixing, surface gravity, or elemental abundances may play as important a role as temperature in setting the atmospheric chemistry of brown dwarfs as they approach planetary masses.

COURTESY TRENT DUPUY

ASTRO**NEWS**

SHOEBOX SATELLITES. On November 19, the Johns Hopkins Applied Physics Lab launched two experimental "cubesats," tiny satellites weighing less than 5 pounds (2 kilograms) and designed to do national security and space-science work.



REVISED REMNANT. Astronomers recently downsized the black hole in an ultraluminous X-ray source (circled) in spiral galaxy M101. Instead of being 100 to 1,000 times our Sun's mass, as previously thought, the black hole is between 20 and 30 solar masses.

X-RAY: NASA/CXC/JHU/K. KUNTZ, ET AL.; OPTICAL: NASA/ESA/STScI/JHU/K. KUNTZ, ET AL.; INFRARED: NASA/JPL-CALTECH/STScI/K. GORDON (M101); HUBBLE/NASA/STScI (INSET)

This black hole is too bright

The extreme gravity of a black hole attracts nearby material, funneling it into what's called an accretion disk. Friction among gas particles within the disk causes it to glow across a range of wavelengths. When this emitted radiation balances the inward gravitational pull, scientists say the black hole has reached the Eddington limit. Because each black hole's limit depends on its mass, they have a way to measure the black hole's weight.

After studying the light output of an ultraluminous X-ray source in spiral galaxy M101, called M101 ULX-1, researchers thought the source was a black hole between 100 and 1,000 times the Sun's mass. However, observations and the following analysis reported in the November 28 issue of *Nature* suggest instead that the black hole is between 20 and 30 solar masses.

Ji-Feng Liu of the Chinese Academy of Sciences in Beijing and colleagues came to this conclusion after studying M101 ULX-1's spectrum, which plots the detected brightness of each wavelength. From that, they learned that the black hole's companion — the object that donates material to the accretion disk — is a Wolf-Rayet star with 19 solar masses. A wind of particles and radiation flows from the star and likely feeds the black hole's accretion disk. The team also determined that the two components of the binary system complete a full rotation around each other in 8.2 days. From those two pieces of information, Liu's team calculated the mass of the black hole: 20 to 30 times the Sun.

This stellar-mass black hole is much more energetic than it should be given its mass; the researchers refer to the object as having super-Eddington luminosity. "These findings show that our understanding of black hole accretion is incomplete and needs revision," says Liu. **— L. K.**

ASTRO**NEWS**

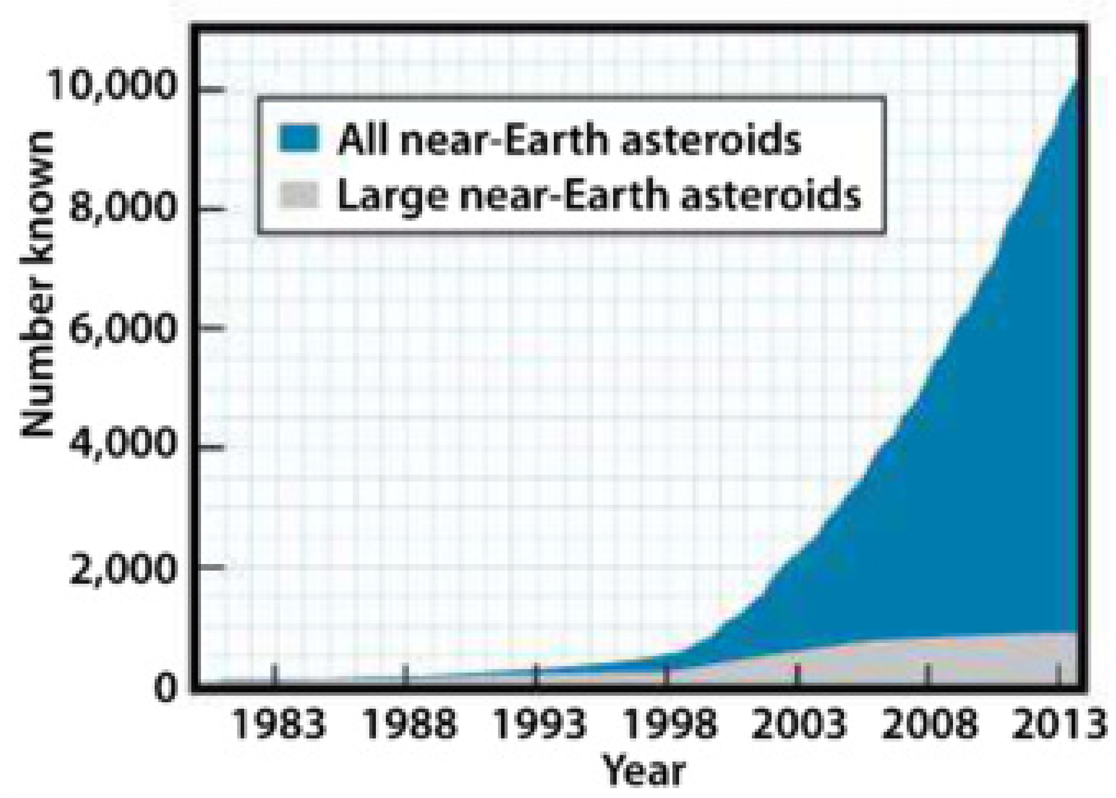
More material, bigger sun

Astronomers studying star-formation sites within the constellation Orion have found that where suns form might dictate their masses. Using the infrared and submillimeter detectors on the European Herschel Space Observatory, the scientists spied hundreds of embryonic stars in two different types of environments. One group was forming along dense filaments of gas while the other group survived "in the field" and not on a filament.

The team calculated the mass ranges of forming stars in both environments and found that those on the filaments weigh about four times as much as the others. The astronomers think this difference is because there is more gas and dust for the filamentary suns to accrete, compared to the field stars. The team's finding appeared in the November 10 issue of *The Astrophysical Journal Letters*. — **L. K.**

FLEDGLING STARS. After analyzing Herschel Space Observatory data of the Orion A complex, astronomers found that stars along filaments of dense material grow to be more massive than those that form elsewhere. ESA/HERSCHEL/PH. ANDRÉ, D. POLYCHRONI, A. ROY, V. KÖNYVES, N. SCHNEIDER FOR THE GOULD BELT SURVEY KEY PROGRAMME

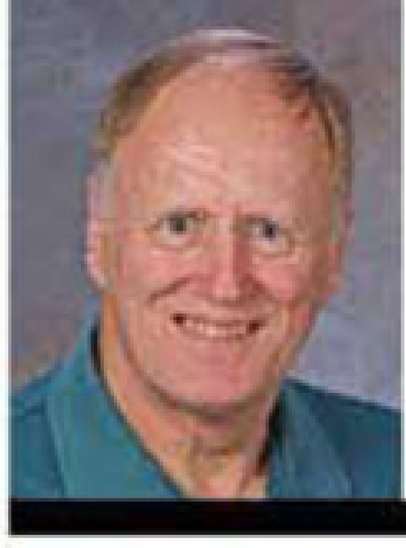
COUNTING ASTEROIDS CLOSE TO EARTH



As of mid-November 2013, the official count of near-Earth asteroids had reached 10,356.

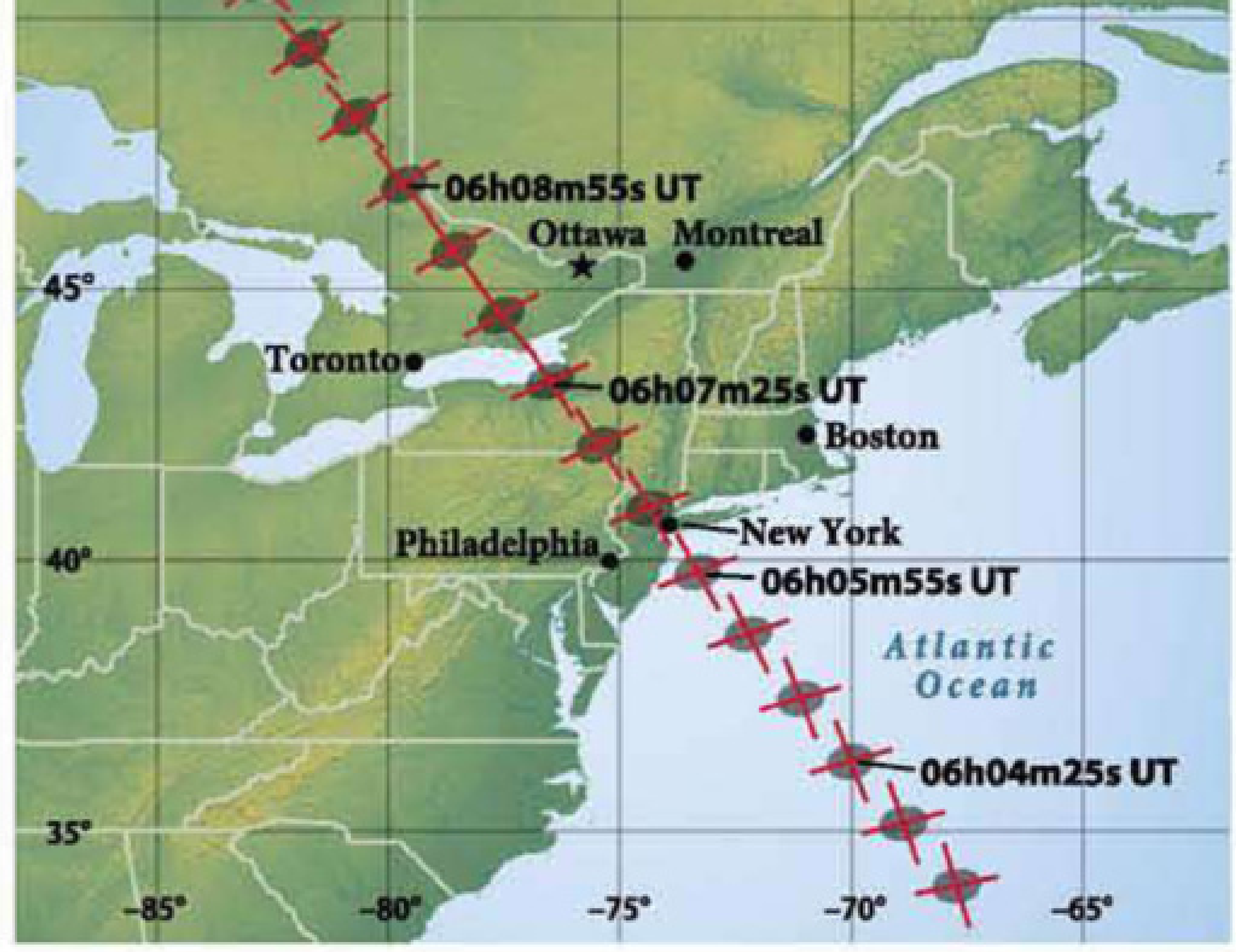
FAST FACT

TARGET EARTH? Although astronomers have discovered hundreds of thousands of asteroids, only a small percentage ever comes close to Earth. The number of known so-called near-Earth asteroids (NEAs) has skyrocketed in the past few decades as astronomers have developed better techniques to find them. Scientists estimate that they have discovered more than 90 percent of large NEAs (those bigger than 0.6 mile [1 kilometer] across); they hope to reach the same proportion of ones at least 460 feet (140 meters) across. *ASTRONOMY:* RICHARD TALCOTT AND ROEN KELLY, AFTER ALAN B. CHAMBERLIN (JPL)



OBSERVING**BASICS**

BY GLENN CHAPLE



On March 20, the asteroid 163 Erigone will occult 1st-magnitude Regulus in Leo. Viewers along a 67-mile-wide (108 kilometers) path across the northeastern United States can witness the event. *ASTRONOMY*: ROEN KELLY, AFTER ALDO VITAGLIANO

Asteroid occultation

Witness Regulus "disappear" from the confines of Leo for a few seconds this month.

In astro-speak, an "occultation" is the passage of one celestial body in front of another, temporarily hiding it from view. A total solar eclipse, when the Moon occults the Sun, is the most spectacular example. The Moon is a veritable occulting machine, its half-degree-wide disk frequently eclipsing bright stars and, on rarer occasions, planets.

Because planets' disks appear much smaller than the Moon's, the occultation of a star by a planet is much less common. Two of the three more notable in recent times were the Mars occultation of Epsilon (ε) Geminorum on April 7, 1976, and the July 3, 1989, Saturn occultation of 28 Sagittarii. But the biggie was Uranus' occultation of the star SAO 156687 on March 10, 1977, which led to the serendipitous discovery of that planet's rings.

Asteroids also occult stars. Their disks may be minuscule compared to those of the Moon and planets, but their sheer numbers guarantee frequent stellar encounters. In fact, you can anticipate one or two each month from your location, though most involve faint stars and require telescopic aid to see.

Two websites, Steve Preston's World Wide Prediction Site (http://asteroidoccultations.com) and Derek Breit's Regional Asteroid Path Maps for the United States (www.poyntsource.com/New/index.htm), list and provide data on pending asteroid occultations of stars brighter than magnitude 12.5 (with a few omissions for extremely faint asteroids). Between the two, you'll get information on date and time, asteroid and star magnitudes, area of visibility (a sweeping path whose width approximates the asteroid's diameter), and the magnitude drop and duration in seconds. A map of the occultation ground track and a sky chart showing the location of the star and occulting asteroid round out the information.

Again, nearly all asteroid/star occultations require telescopic aid, as the occulted star is usually too faint to view with the unaided eye. This month, however, there's a notable exception. During the early morning hours of March 20, a rare occultation of a 1st-magnitude star by an asteroid occurs when 163 Erigone (the number means Erigone was the 163rd asteroid in order of discovery) occults Regulus (Alpha [α] Leonis). Observers along a 67-mile-wide (108 kilometers) track stretching northwestward from the North Atlantic, across New York and eastern Ontario, and on to the Arctic will have a ringside seat to this event.

On the date of the occultation, Erigone will be a magnitude 12.4 speck. You'll need a 6- to 8-inch telescope if you wish to monitor the asteroid approaching Regulus. Once Erigone becomes lost in the glare of its brilliant target, it's time to abandon telescope and gaze skyward. At the predicted moment (shortly after 2:06 A.M. EDT for landfall somewhere on Long Island), Regulus will suddenly blink out, offering the eerie sight of the constellation Leo minus its 1st-magnitude star. Regulus will remain invisible for up to 14 seconds before suddenly reappearing.

If you plan to travel to view the Erigone/Regulus occultation, be aware that scientists don't precisely know the orbits of all asteroids, so the predicted path and times will require frequent revisions. Be sure to consult Preston's and Breit's sites for updates, especially as the target date nears. Also be forewarned that March weather in this part of North America is often beset by cloudy skies. (I know from sad experience. I live here!)

If a trek to view this spectacle is out of the question, wait a decade. The next asteroid occultation of a 1st-magnitude star will happen December 12, 2023, when 319 Leona crosses paths with Betelgeuse (Alpha Orionis). The ground track sweeps westward from Turkey, across the Mediterranean that touches southern Greece, Italy, and Spain, and then onward across the Atlantic to Cuba.

Still, the much more common occultations of faint stars are worthwhile events. In recent decades, professional and amateur astronomers have been turning their attention to asteroid/star occultations. The events supply precise information that lead to a more accurate determination of the sizes and orbital positions of asteroids.

If you want to see an asteroid "take out" a star from your backyard, whether in a serious attempt to glean data or to simply be a spectator, let Preston and Breit be your guides. Beyond those, for a complete guide to occultations, from lunar to asteroidal, refer to David Dunham's International Occultation Timing Association (IOTA) site at www.lunar-occultations.com/iota/iotandx.htm.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: a total lunar eclipse. Clear skies!

FROM OUR INBOX

Welcome back to the dark side

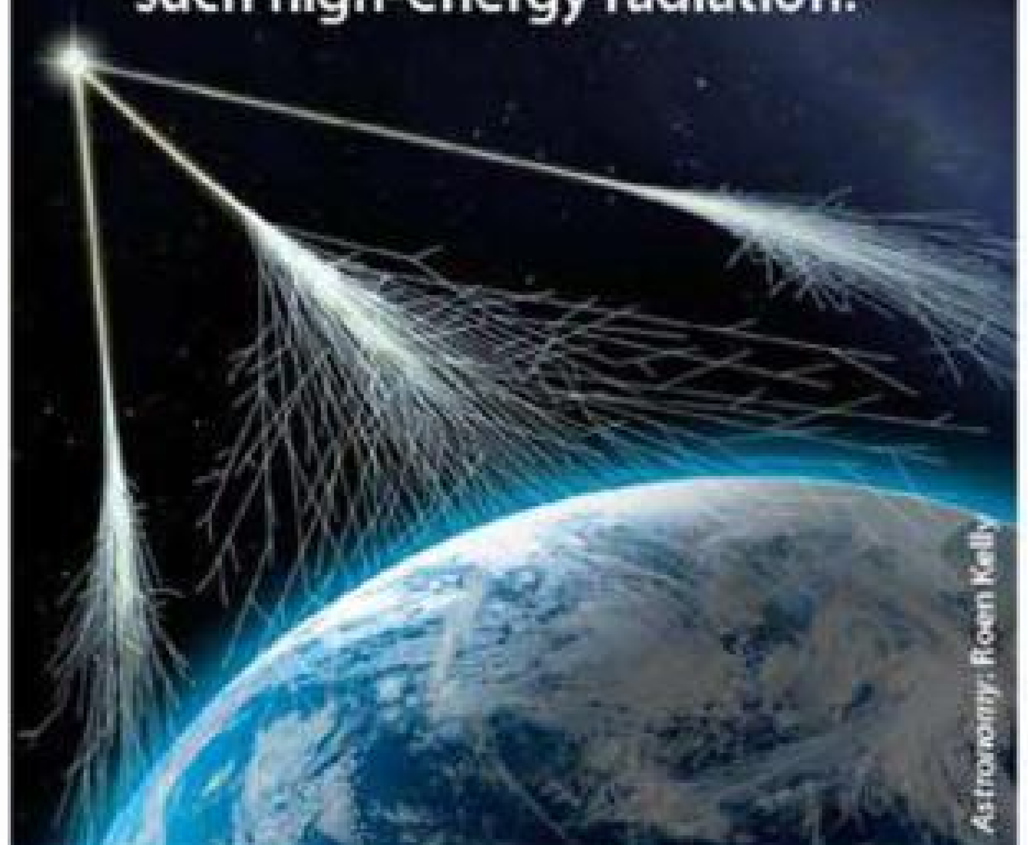
I purchased my first issue of *Astronomy* in 1994, when I was 16. After a lengthy hiatus, I returned as a subscriber a couple of years ago. I was pleased to see that although some changes have taken place, all the elements that have always made *Astronomy* a leader in its field are still there: the in-depth yet easy-to-understand articles, the thorough equipment reviews, the comprehensive "The Sky this Month" forecasts, and all the special columns covering every aspect of our hobby. In short, thanks for a great magazine, and I'm very happy to be back! — **Gaute Hjartaaker,** Oslo, Norway

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

COMING IN OUR NEXT ISSUE

Solving the mystery of cosmic rays

What natural particle accelerators are powerful enough to produce such high-energy radiation?

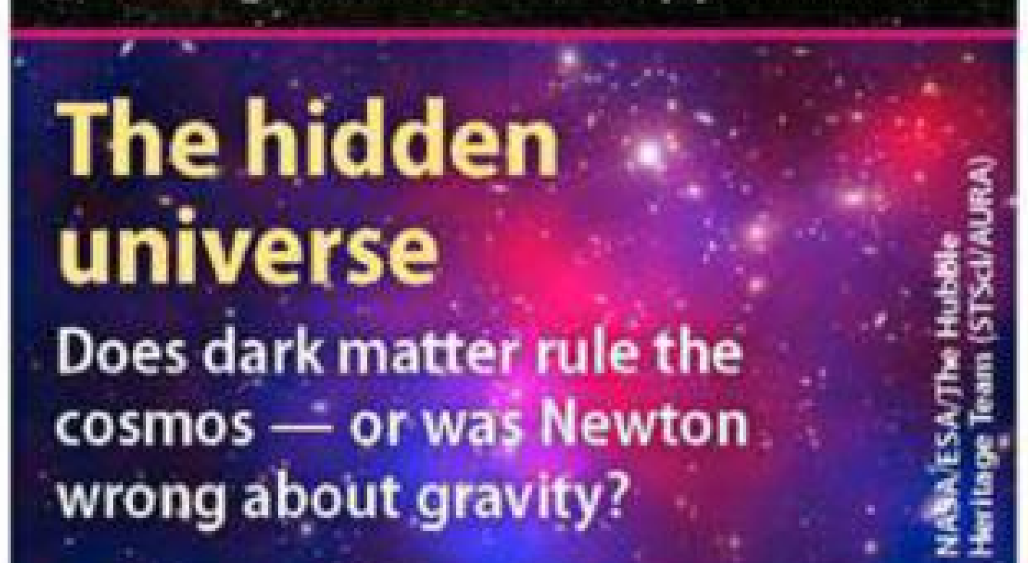


The next search for Earth-like worlds

The Kepler spacecraft has found candidate planets galore. What happens now?

The hidden universe

Does dark matter rule the cosmos — or was Newton wrong about gravity?



PLUS

- View Ceres and Vesta at their best
- Observe April's spectacular lunar eclipse
- A solar-powered observatory for the home
- How Terry Mann captures Earth and sky
- *Astronomy* tests Meade's new 10-inch SCT

Astronomy magazine

IN MEMORIAM. Fred Kavli, who gave more than $200 million to science research, positions, conferences, and prizes, died November 21.

SPACE SCIENCE UPDATE

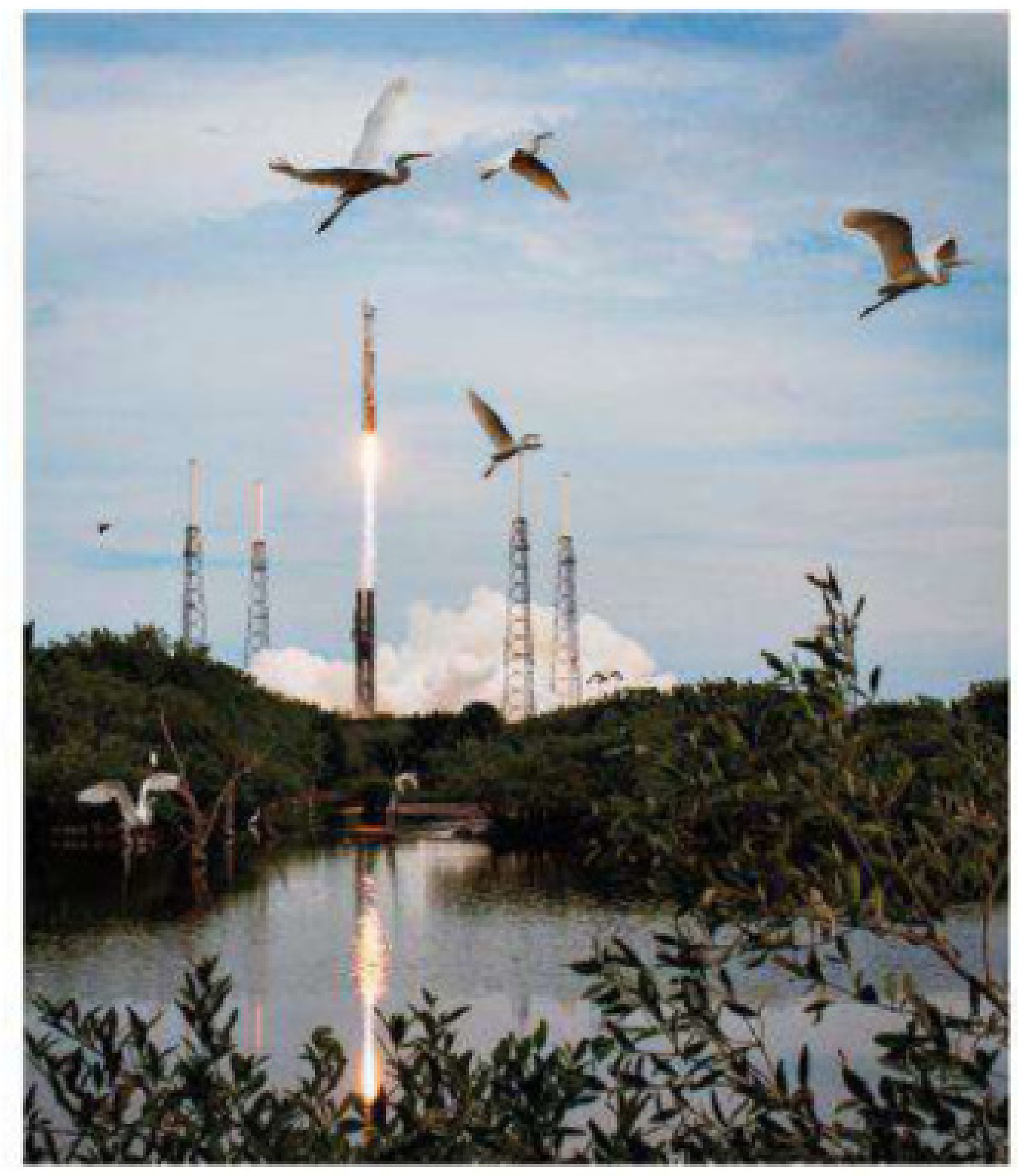
NEW MISSIONS TO THE RED PLANET

Mars can expect more visitors after two November launches. On the 5th, the Indian Space Research Organization launched its Mars Orbiter Mission (MOM) to showcase the country's space technologies. Then on November 18, NASA launched the Mars Atmosphere and Volatile Evolution (MAVEN) mission.

MOM is India's first martian probe. After takeoff, the spacecraft orbited Earth and experienced six engine burns to raise its path farther above our planet's surface. On December 1, the spacecraft broke out of Earth's gravitational clutch and began its 10-month journey to Mars. Once MOM arrives at the Red Planet, it will begin a six-month primary mission that will take it 227 miles (365 kilometers) from the martian surface at nearest approach to 49,700 (80,000km) from the surface at its farthest orbital point.

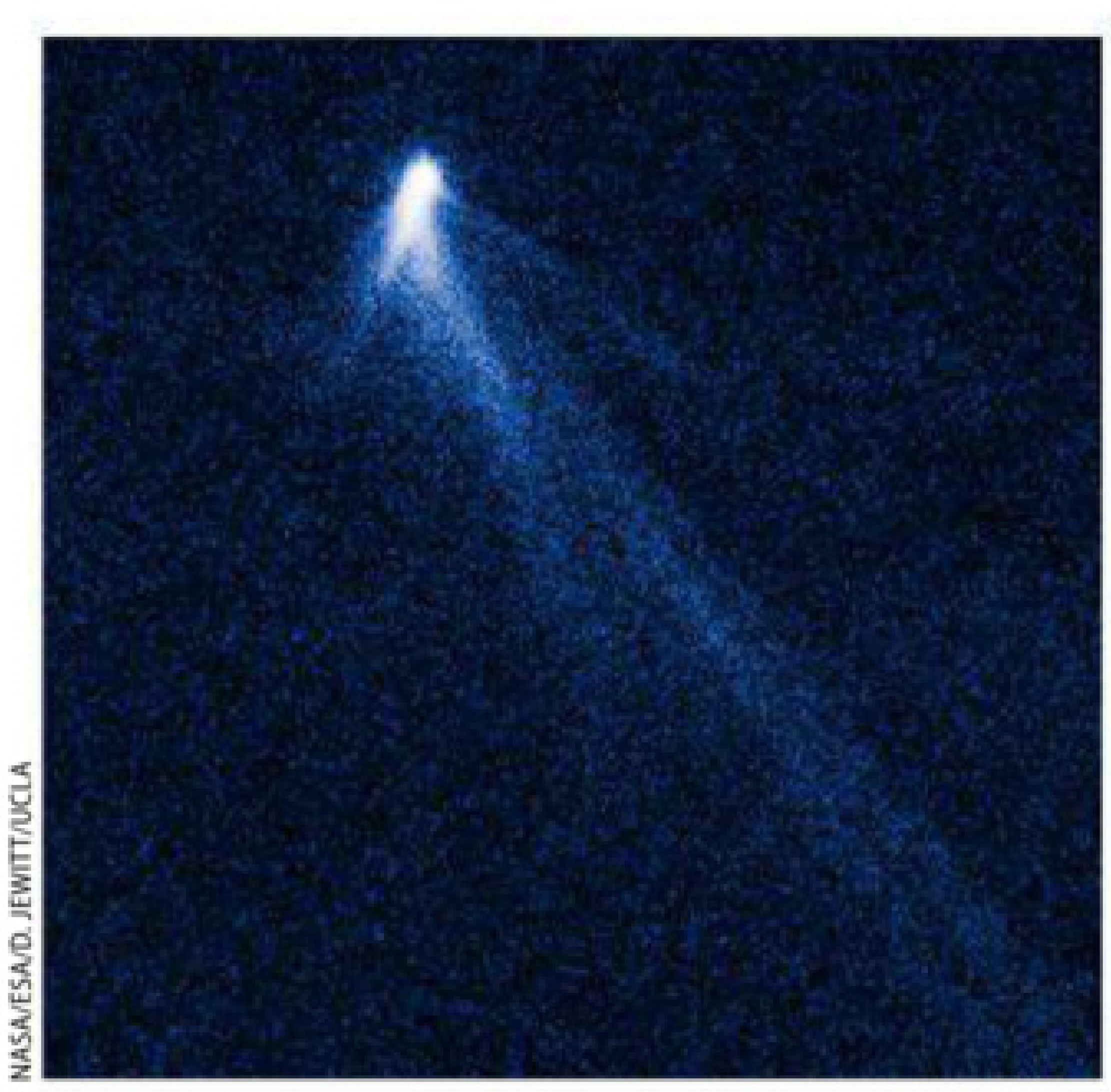
Scientists expect to use the probe's images and other data to learn about the martian weather system and to search for methane. The Indian Space Research Organization also stresses that MOM is testing interplanetary travel technologies.

The MAVEN spacecraft also will arrive at Mars in September, but its orbit will bring it much closer to the planet. It will fly 93 miles (150km) from the surface, passing through the martian upper atmosphere, at closest approach and reach about 3,730 miles (6,000km) at its farthest point. Throughout its one-year primary mission, the probe will dip to 77 miles (125km) above the surface five times to capture information about the top of the lower atmosphere.



JOURNEY BEGUN. NASA's Mars Atmosphere and Volatile Evolution is one of two missions to the Red Planet that launched in November. The other is India's Mars Orbiter Mission. NASA/BILL INGALLS (LAUNCH)

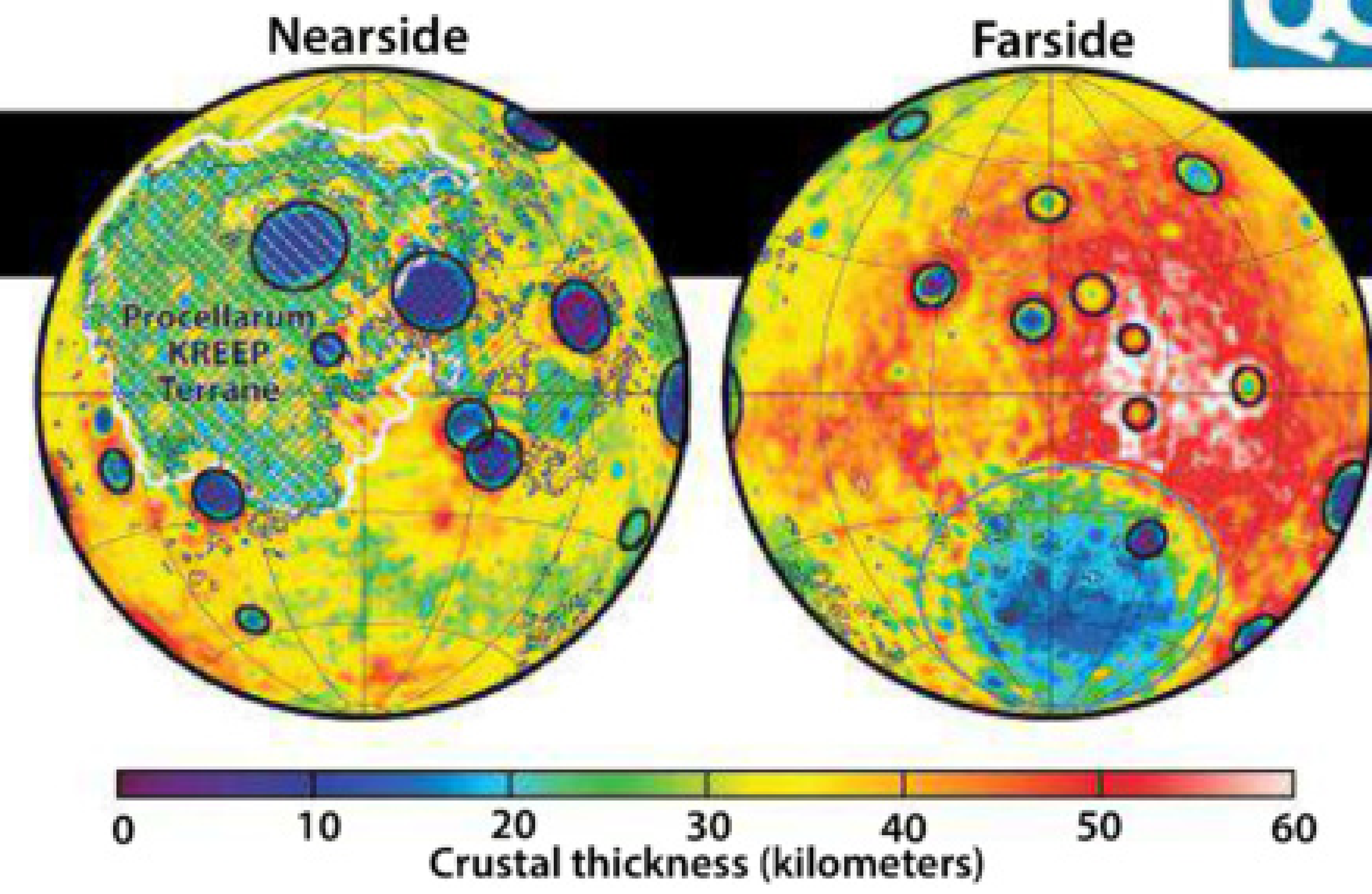
Evidence from other orbiters and landers shows that Mars' atmosphere and climate have changed over time and that liquid water once flowed across the Red Planet. Scientists want to know where the bulk of the martian atmosphere went and what caused the loss. MAVEN will provide information about the current atmosphere's composition, how it's changing, and how the Sun's radiation and solar wind affect it. "With MAVEN, we're exploring the single biggest unexplored piece of Mars so far," says Principal Investigator Bruce Jakosky of the University of Colorado Boulder's Laboratory for Atmospheric and Space Physics. Mission scientists have tested the craft's eight instruments to ensure they will work upon MAVEN's arrival at Mars. — **L. K.**



NASA/ESA/D. JEWITT (UCLA)

Asteroid dresses up as six-tailed comet

INCOGNITO ASTEROID. On September 10, the Hubble Space Telescope first snapped a shot of asteroid P/2013 P5, which the Pan-STARRS telescope in Hawaii had revealed as a particularly fuzzy-looking rock. Hubble, however, saw that its blurriness actually resolved into six dusty tails sprouting from its surface. This comet-like behavior, scientists think, may be because the asteroid is spinning so fast that its surface is flying apart, causing periodic dust ejections, six remnants of which appear in the Hubble image. A second Hubble picture, taken September 23, revealed a different view of this volatile rock. The discoveries appeared in the November 20 issue of *The Astrophysical Journal Letters*. — **S. S.**



THIN CRUST. Data from NASA's Gravity Recovery and Interior Laboratory have allowed astronomers to produce a map of the Moon's crust that shows a far thinner crust on the lunar nearside. NASA/JPL-CALTECH/S. MILJKOVIC

ASTRONOMICAL POWER BILLS

SAVE PENNIES. If you think your utility bills are high, consider how much a pulsar, if powered by coal, would pay the electric company for its monthly energy. The numbers are how many times as much as the world's gross domestic product the energy cost would be. *ASTRONOMY*: SARAH SCOLES AND ROEN KELLY

FAST FACT

Earth's core produces just a millionth of a percent as much energy as a brown dwarf — less than a pixel on the dollar bill.

833

The number of candidate exoplanets in newly analyzed Kepler spacecraft data, NASA announced November 4.

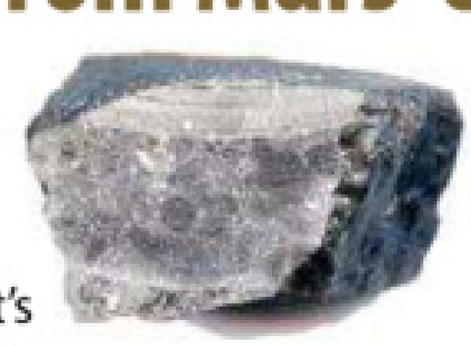
Lunar farside tells more accurate history

Scientists have long used the large impact basins on the side of the Moon facing Earth as evidence for a period of intense pummeling of the inner solar system by giant asteroids about 4 billion years ago. Such massive craters produced during this time, called the Late Heavy Bombardment, could result only from equally massive impactors. Yet the Moon's farside doesn't have such giant impact basins, and new research published November 8 in *Science* explains why.

Using data from NASA's twin Gravity Recovery and Interior Laboratory spacecraft, which orbited the Moon for nine months in 2012, scientists from the Massachusetts Institute of Technology and the University of Paris generated a highly detailed map of the lunar crust, which showed that the crust is thicker on the farside. Combining this knowledge with evidence that the nearside also had higher internal temperatures due to volcanic activity, the researchers generated simulations of asteroid impacts to both sides.

"Impact simulations indicate that impacts into a hot, thin crust representative of the early Moon's nearside hemisphere would have produced basins with as much as twice the diameter as similar impacts into a cooler crust, which is indicative of early conditions on the Moon's farside hemisphere," says lead author Katarina Miljkovic of the University of Paris. Such results indicate that the lunar farside may better reflect the size distribution of the Late Heavy Bombardment asteroids. — **K. F.**

Meteorite from Mars' crust found



CRUSTY PLANET. This sample of Mars' crust is the first such meteorite scientists have found on Earth. LUC LABENNE

A martian meteorite known as NWA 7533 that landed in the Sahara desert tells the story of the Red Planet's early formation history, scientists announced online November 20 in *Nature*. It is the first meteorite known to come from Mars' crust.

When Munir Humayun of Florida State University in Tallahassee and his team studied NWA 7533 using a powerful microprobe, its crystals dated it at 4.4 billion years old. "This date is about 100 million years after the first dust condensed in the solar system," says Humayun. In other words, Mars' crust existed within the first 100 million years of planet formation, around the same time the crusts of Earth and the Moon came into existence.

Based on the rock's composition, the team could tell where it came from, geographically. It was ejected from the southern highlands, an area from which scientists have never before found a sample.

It has high concentrations of trace metals like iridium, suggesting that meteorites once pummeled its hometown. "This cratered terrain has been long thought to hold the keys to Mars' birth and early childhood," says Humayun. NWA 7533 surely will reveal more secrets about the area and martian history as the investigation continues. — **S. S.**

COSMIC**IMAGING**

BY ADAM BLOCK

Compelling contrast

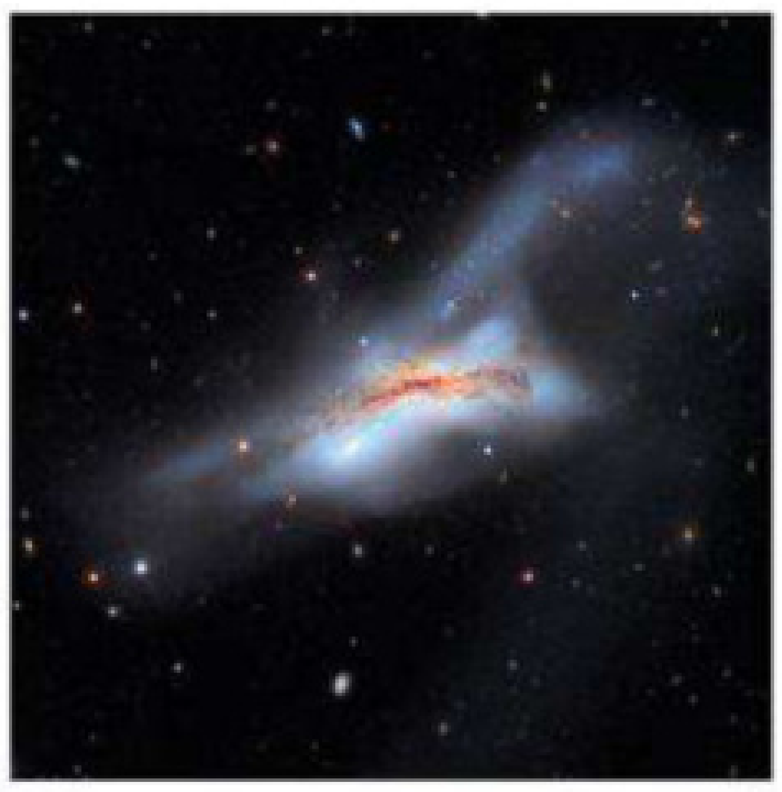
Editor's note: Welcome to the first column by world-renowned astroimager Adam Block. Block currently heads up the University of Arizona's Mount Lemmon SkyCenter and has been teaching imaging techniques for two decades. By following his advice, you will become a better astroimager.

Let me begin by saying what an honor it is to author a column in *Astronomy* on image processing. I have been reading this magazine my entire life, and to be part of the burgeoning community of digital astrophotographers through it is incredible. I also bow to my predecessor, Tony Hallas, for blazing a trail and writing a concise column on the subject, which will serve as a template for my future articles.

Image processing is a mix of both science and art. The science comes from the fact that each picture we take is a measurement. Handling the values we obtain in a rigorous way through standard processing steps enables us to get the most from our data. The art comes from the choices we make about which attributes of the data we want to highlight.

I considered addressing my overall processing philosophy first, but space is limited. Instead, I'll highlight a few critical themes I will revisit in future articles.

First, most processing steps are small and incremental, but you will see their cumulative effects in your final images. For this reason, I'll always provide Internet links to the objects I discuss. Due to the vagaries of the printing process, the view on your monitor may better represent the effects I describe here.



NGC 520 is a pair of colliding galaxies in the constellation Pisces. The collision has created a long tidal tail of material. The author shows you how to increase the contrast of that feature without increasing noise or losing detail. To view this image online, head to http://skycenter.arizona.edu/gallery/Galaxies/NGC520.

Second, I generally choose global adjustments whenever possible. They are easier (and faster) to do, and they help avoid unintended artifacts.

Finally, my style is what many would call "naturalistic," and I'll add that it's also slightly conservative. I value maintaining certain truths about the target in terms of brightness, color, and detail. For example, galaxies are almost always brighter in their centers, so I choose to display them this way even if it means the inner structure doesn't show up as well.

With this in mind, I offer an artistic processing trick. Certain objects contain wispy and faint structures. The tidal tails of

Spiral galaxy NGC 7497 in Pegasus stands out quite well in this image. The author increased the contrast of the Integrated Flux Nebula around it without losing the fine details in the galaxy. To see this image online, go to http://skycenter.arizona.edu/gallery/Galaxies/NGC7497.

galaxies as well as the galactic cirrus in our home galaxy are the kinds of challenging details that add impact to an image. At some point, that image is as bright as it can be (based on the quality of the data) without showing the deleterious effects of noise and imaging errors.

So, you have those wisps, and if you could just make them stand out a bit more, you would be happy with the picture. To increase the contrast, you must either brighten the image, which would reveal noise, or make the sky darker and potentially lose the detail you are striving to retain! What to do?

Using *Photoshop*, make two copies of your color image as two more layers. I labeled them in the screen shot for clarity. On the bottom layer, apply the "Equalize" effect (under "Image" and "Adjustments"). Blend the middle layer with the bottom layer using the "Multiply" blending mode. Finally, on the top layer change the "Opacity" to reveal this multiplicative contrast effect, or MCE, my name for this tool.

Here's how it works. The "Equalized" version of your image displays everything that is

ALL IMAGES: ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The author took this screen shot of *Photoshop* to illustrate some of the steps he took and how the "Equalized" image differs from the original.

even the slightest brightness above the sky value as nearly white. Don't worry about the colors you may see. (This tool is also wonderful at showing all of your flat field errors and other gradients.) This crazy image is now something like a map. Anything bright in the image will remain visible when blended with "Multiply." Your wispy clouds and tidal tails will remain at their original brightness level, while the sky will become darker. This is a simplified version of a threshold mask that I'll explain in a future article.

When you blend with "Multiply," you get a single result. Use the original image to let this effect come through by changing the "Opacity." Applying this tool modestly to objects with faint structures can make those features stand out without your applying arbitrary selective techniques by hand. In the case of NGC 520, the tidal tail reaches out to the nearby companion galaxy UGC 957, and with NGC 7497, the dusty galactic cirrus billows with high contrast.

In next month's column, I'll describe how I put together a comet image.

FROM OUR INBOX

Cometary reflections

In the summer of 1957, I was on summer vacation from the American high school I was attending in Munich. Every evening after sunset — with a dark sky but with zillions of stars visible — Comet Arend-Roland (C/1956 R1), with its double tail, was bright. Night after night, I stared at the sensational object that seemed to be stationary among the pinpoint-sized stars but in a different position among them each evening. Comet ISON (C/2012 S1) now joins Arend-Roland in my mind. — **Jan Perry Esten,** Florissant, Colorado

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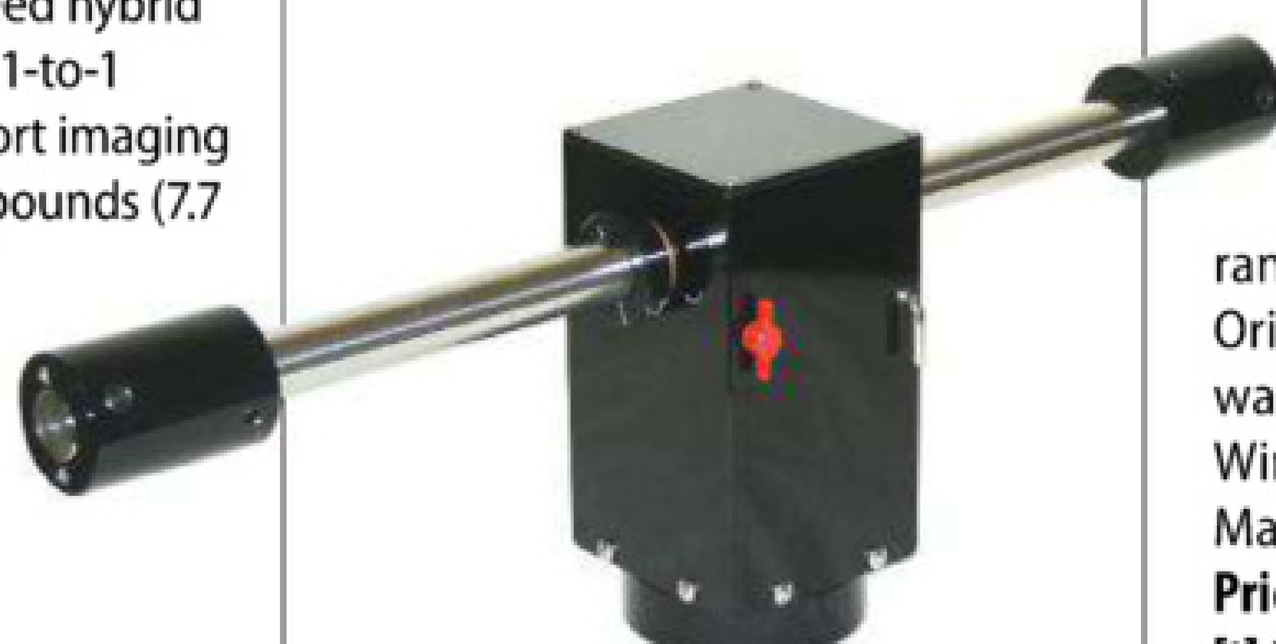

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Price: $175
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WEBTALK

What's new at Astronomy.com.
BY KARRI FERRON

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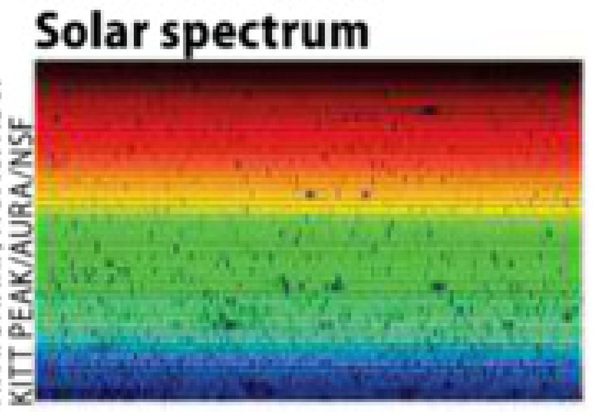
Astronomy 101

The interesting and odd of the cosmos

New to astronomy and looking for detailed background information about the coolest objects and concepts that make up the field? What are quasars? How do scientists understand astronomical distances? What relationship do chemistry and astronomy have? To gain insight into these questions and much more, check out the Astronomy.com *Astronomy 101* video series — a fun introductory course that's easy to follow.

Through quarterly new episodes, the staff's editors help viewers understand the intriguing objects and concepts that make up the cosmos. Along with its sister series, *Cosmology 101*, *Astronomy 101* covers everything from galaxies and nebulae to the Big Bang and black holes. Each episode includes discovery information, formation processes, and recent advancements in scientists' understanding, all illustrated with spectacular photos and detailed diagrams. The 2014 season will cover topics such as the Milky Way, brown dwarfs, cosmic rays, and radio astronomy. Gain knowledge about the wonders of the universe in no time by visiting **www.Astronomy.com/101**.

Solar spectrum



N. A. SHARP, NOAO/NSO/KITT PEAK/AURA/NSF

Quasar 3C 273

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The Sky this Week

This daily digest of celestial events highlights the brightest objects you can observe each night. In 10-day increments, learn when and where to spot each planet, the best meteor showers, bright comets and asteroids, notable constellations and asterisms, a few deep-sky objects, and more. Each daily entry offers essential details of the event or object and how to locate it in your sky. See what's happening tonight at **www.Astronomy.com/skythisweek**.

COMMUNITY

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SKYJA

NASA's audacious plan to tow an asteroid to Earth

Mankind's next giant leap into the cosmos may involve small steps on an asteroid captured and brought into lunar orbit. **by Ray Villard**

In the 1967 James Bond film *You Only Live Twice*, an enemy satellite sneaks up behind a manned space capsule, opens clamshell doors, and swallows the craft so it can be hijacked to an enemy base inside a dormant volcano.

Now, NASA is planning to do its own hijacking — not of a spacecraft mind you, but of a 1,000-ton asteroid. The rock won't be landing at a secret Earth base either, but will be placed in a parking orbit around the Moon. More than a memento of deep space, it will be the first solar system body other than the Moon that humans will visit. From it, astronauts will collect primeval material undisturbed since the solar system's formation 4.5 billion years ago.

Targeting an asteroid for a human visit began in earnest in 2010 when President Obama set a sky-high goal for NASA: send a team of astronauts to visit a near-Earth asteroid (NEA) by 2025. Carrying a two-person crew, the new Orion space capsule would be launched on a six-month round-trip journey. It would be a dangerous endeavor largely because solar flares could expose the crew to lethal doses of radiation.

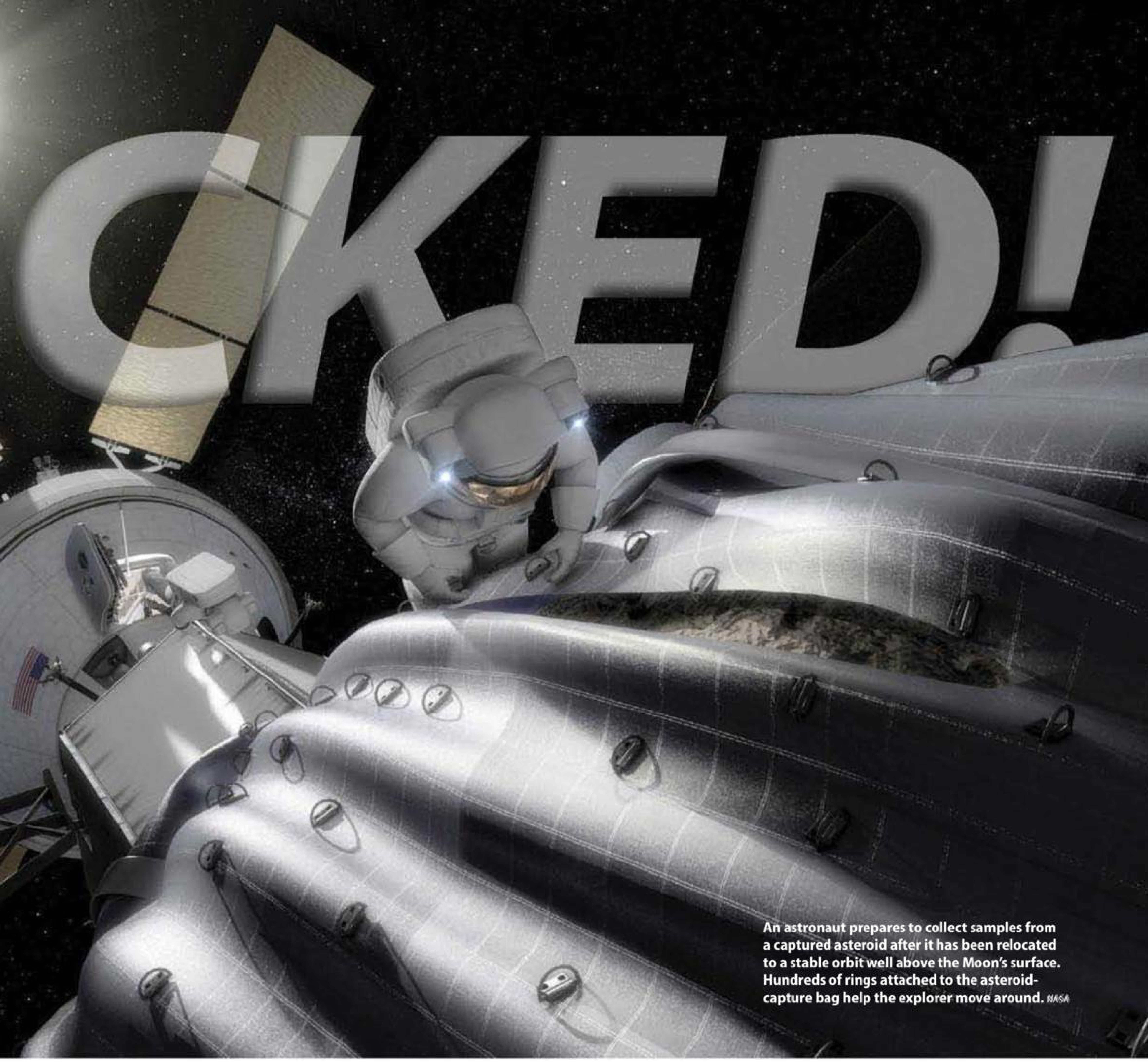
On second thought

But rather than propelling humans on a risky long-duration journey into interplanetary space, what if we brought an asteroid here? Not only would capturing an asteroid be the ultimate rock collector's dream, but it also would mark humanity's first attempt at modifying the solar system with an eye to the eventual permanent settlement of people in space.

This retrieval scheme caught on with the Obama presidency. In April 2013, his administration requested $105 million in NASA's 2014 budget to begin work on a mission to capture a small asteroid, tug it to a position

Ray Villard *is news director for the Space Telescope Science Institute in Baltimore.*

CKED!



An astronaut prepares to collect samples from a captured asteroid after it has been relocated to a stable orbit well above the Moon's surface. Hundreds of rings attached to the asteroid-capture bag help the explorer move around. NASA

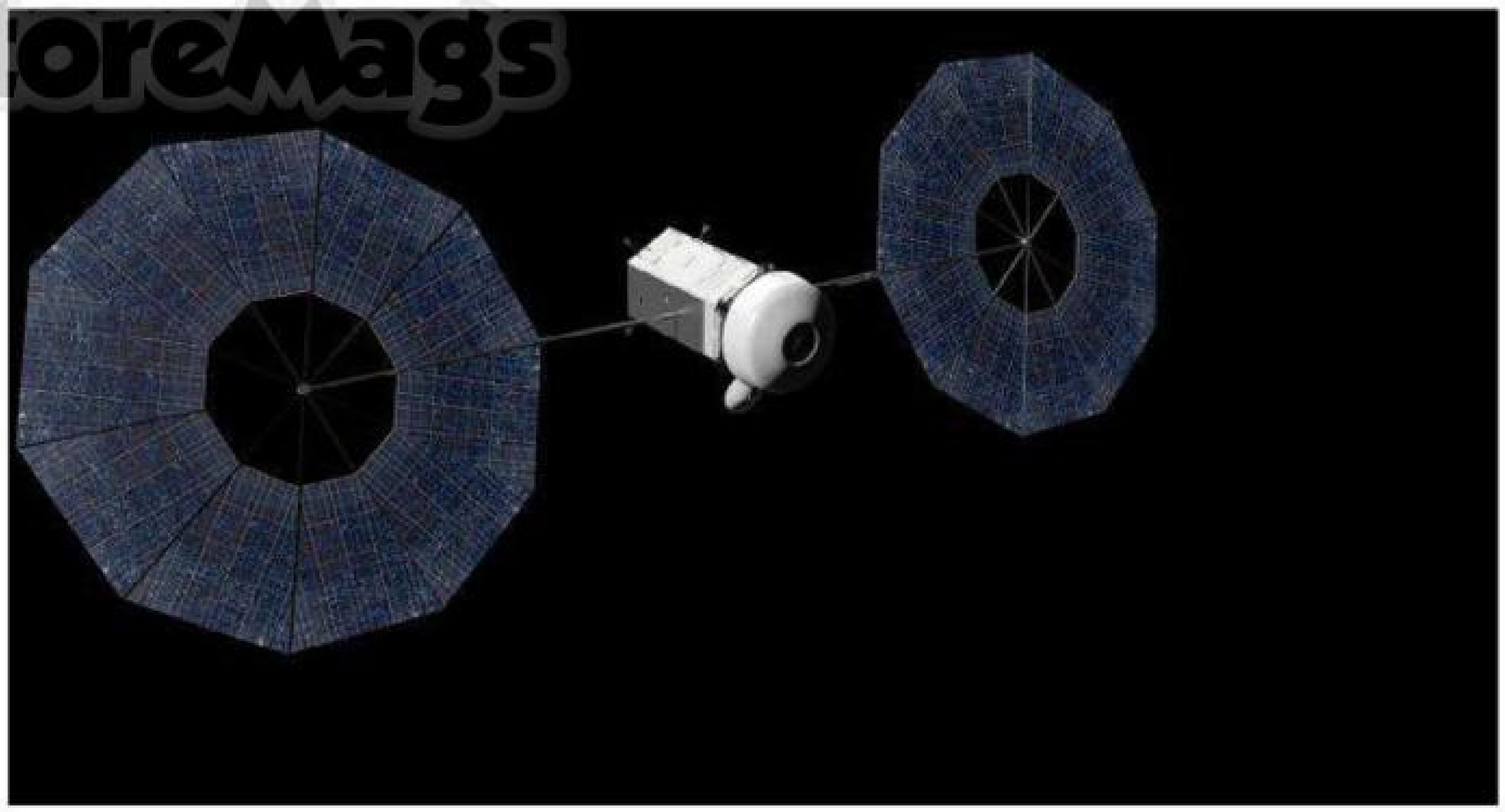
near the Moon, and later send astronauts to study it and return samples to Earth.

The asteroid-capturing robot could launch as soon as 2017, with astronauts visiting the space rock by 2021. This offers a much faster track for sending humans beyond low Earth orbit than the lunar surface or Mars, which both would require the added complexity, payload weight, and expense of building a lander vehicle.

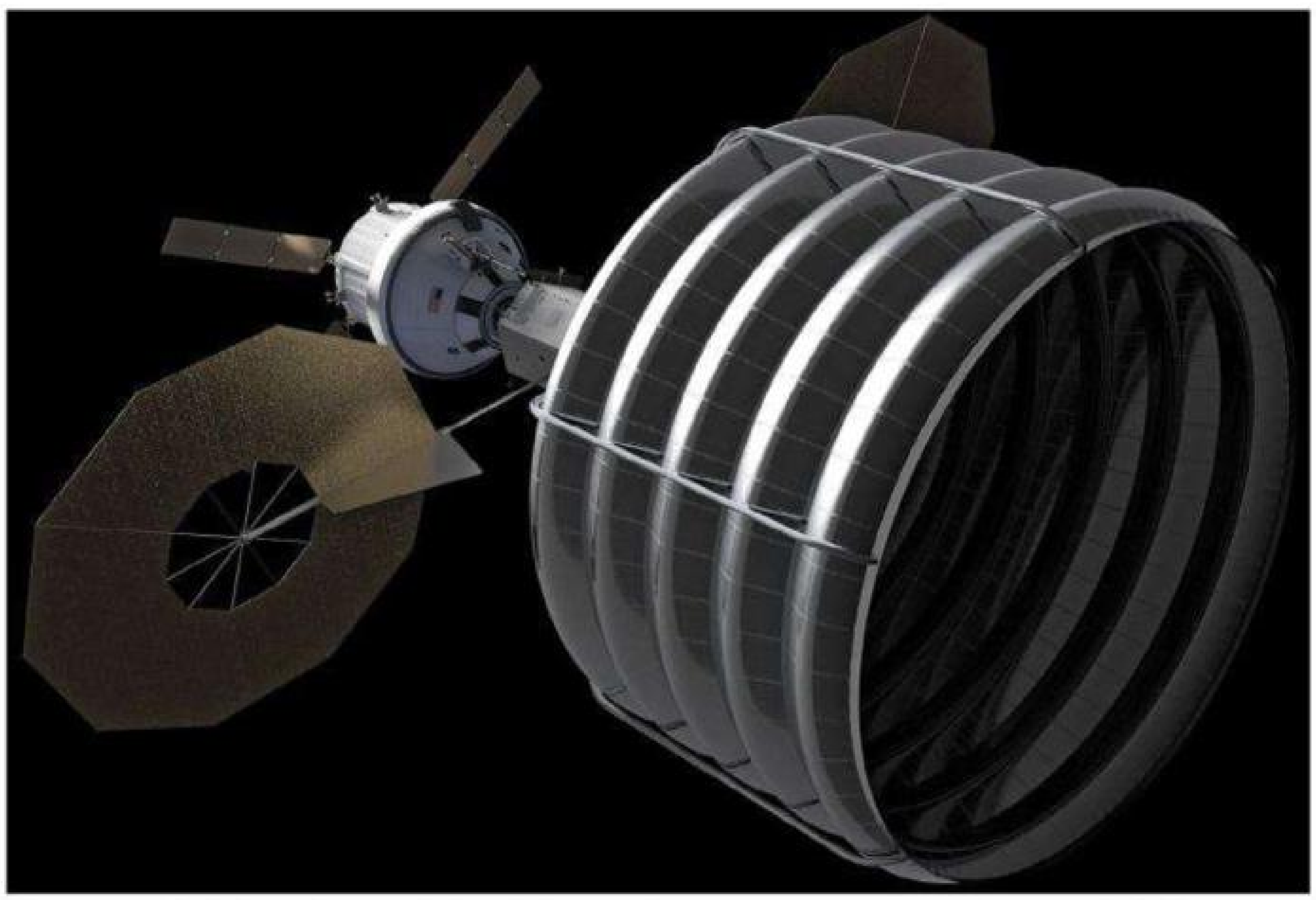
As outside the box as this concept sounds, it covers a lot of desirable bases. Planetary astronomers want to understand potentially Earth-threatening asteroids that are not that much bigger than the one planned for capture. Such a mission also will require NASA to develop further its solar-electric propulsion systems, which drive vehicles by shooting ions out the rear of the spacecraft. Currently, this technology powers a few small interplanetary spacecraft, including the Dawn mission to the main-belt asteroids Vesta and Ceres (see p. 44), but the goal is to do a lot more.

Capturing an asteroid is not a new idea. For decades, science-fiction authors and space futurists have discussed the importance of asteroids to human expansion into space. In 1903, Russian rocket scientist and space visionary Konstantin Tsiolkovsky described snagging asteroids in a paper with the understated title of "The Exploration of the Cosmos by Means of Reaction Motors."

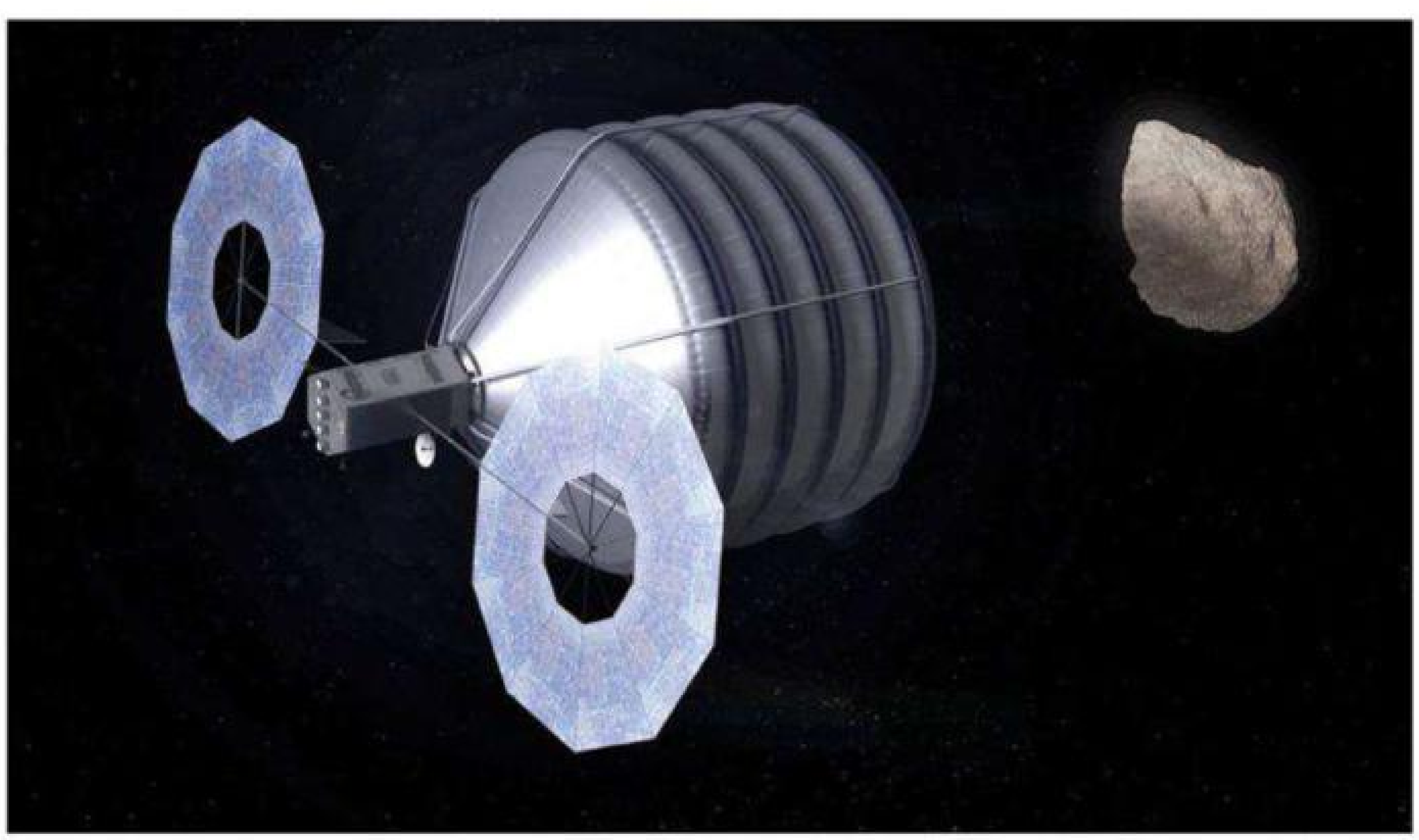
That dream has become feasible thanks to three key developments. First, astronomers now can discover and characterize vast numbers of small NEAs that would be suitable for capture and return. Second, engineers know how to build solar-electric propulsion systems powerful enough to transport a small asteroid. And third, NASA's timetable for sending humans beyond low Earth orbit in the 2020s nicely dovetails with these scientific and technological developments.



Solar panels power the unmanned asteroid-retrieval spacecraft. In this view, the craft is cruising through space with its asteroid-capture mechanism stowed. NASA/ADVANCED CONCEPTS LABORATORY



The spacecraft deploys a large cylindrical "shopping bag" to capture a near-Earth asteroid. If all goes according to plan, NASA will launch the mission in 2017. NASA/ADVANCED CONCEPTS LABORATORY



Onboard computers guide the spacecraft toward its target: a near-Earth asteroid measuring approximately 23 to 33 feet (7 to 10 meters) in diameter. NASA/ADVANCED CONCEPTS LABORATORY

Astronomers have cataloged approximately 10,000 NEAs to date. But scientists don't know the gritty details of exactly what they are made of or even how they hold together. More importantly, humans eventually will have to find a way to divert an asteroid headed toward Earth.

What's more, asteroids could represent the freight cars of the solar system. They can provide the metals and minerals necessary for building large space structures and are a potential source of water for rocket fuel, thirst quenching, and breathable oxygen.

Asteroid hunting

Scientists and engineers defined the general architecture for the asteroid-capture mission during a 2012 workshop sponsored by the Keck Institute for Space Studies and held at the California Institute of Technology in Pasadena. Participants from many institutions investigated how feasible it would be to identify, autonomously capture, and return an NEA to Earth's vicinity.

NASA won't require anything as exotic as a *Star Trek* tractor beam to tow the space rock here. A robotic spacecraft would, quite literally, put the asteroid in a giant shopping bag and tote it home.

Unlike the Bruce Willis character Harry Stamper in the 1998 film *Armageddon*, astronauts could not walk around on the target asteroid. The captured NEA will be only the size of a modest house, some 23 to 33 feet (7 to 10 meters) across. (This is roughly half the size of the NEA that exploded in the atmosphere above Chelyabinsk, Russia, on February 15, 2013.) The pull of gravity from an asteroid this size would be barely measurable.

The most scientifically desirable kind of asteroid for snagging and bringing to Earth is a coal-black carbonaceous C-type asteroid. Carbonaceous asteroids are diverse — they contain a rich mixture of volatile substances like water, complex organic molecules, dry rock, and metals. Although they make up about 20 percent of the known asteroid population, they are hard to find because they are so black.

To carry out what NASA calls the "Asteroid Initiative," astronomers will have to locate asteroids that are both sufficiently small and follow orbits close to that of Earth. The challenge is to find candidates that are large enough, and thus bright enough, to be detected yet small enough to be towed by a spacecraft.

Ground-based observatories can discover such asteroids only when they pass extremely close to Earth. The upcoming

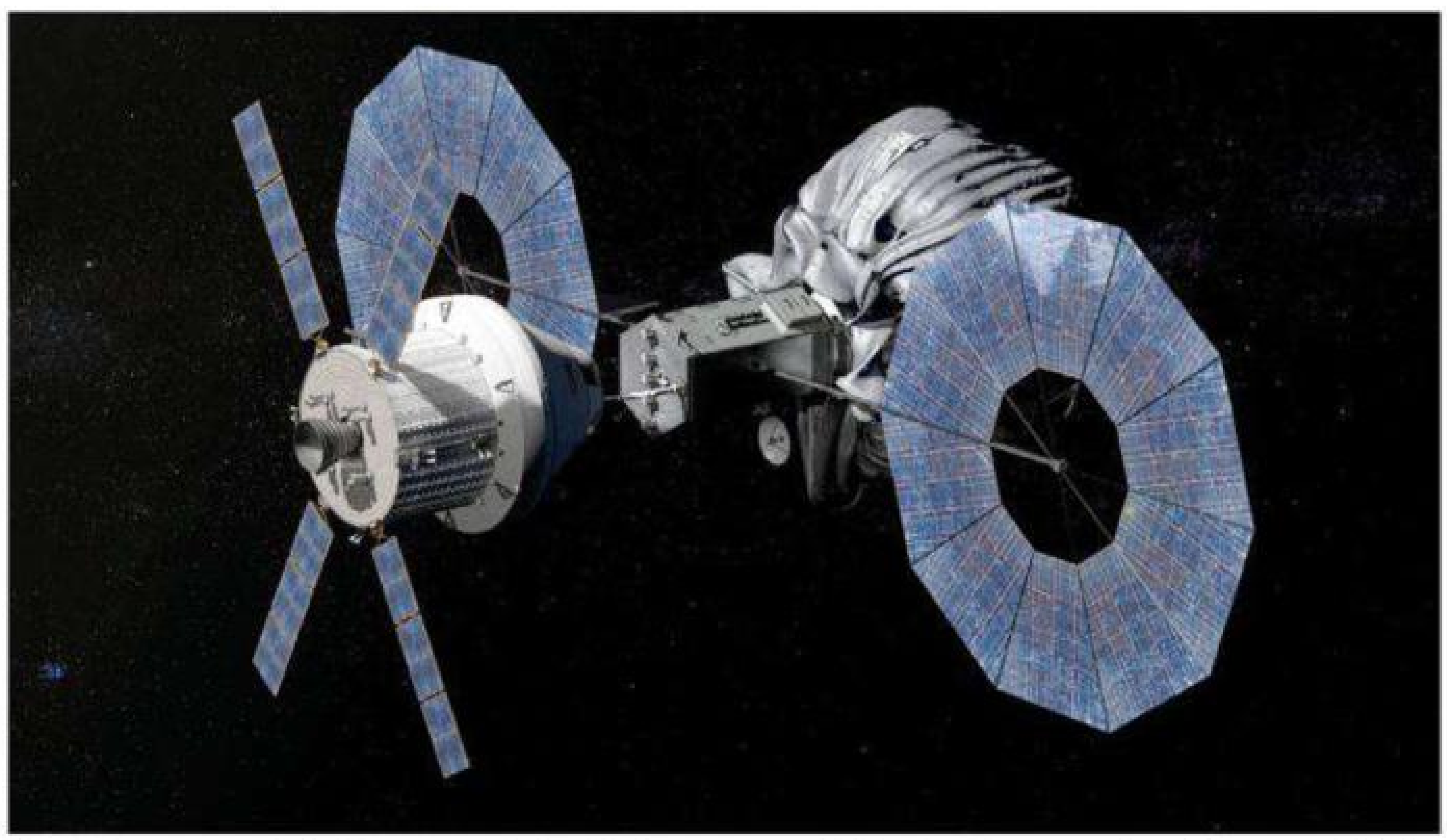
Large Synoptic Survey Telescope, scheduled for first light in 2018, will be 150 times more efficient at finding candidates than the best current telescopic searches.

In order to bring one of these objects home, it must have orbital parameters that nearly match Earth's, where its closest approaches to our planet are spaced no more than a decade apart. One target might be the asteroid 2008 HU_4, which researchers estimate to be roughly 23 feet (7m) across. This asteroid will make its next close approach to Earth in 2016 and a subsequent one in 2026.

The asteroid retrieval spacecraft likely will feature two large "butterfly-wing" solar arrays extending from a central body, or bus. The solar panels will generate 40 kilowatts of power to run both the electric propulsion system and the large inflatable capture mechanism.

Propellant tanks will carry 12 tons of xenon for five thrusters, only four of which will operate at any given time. Inside the thrusters, electrons will bombard the xenon atoms and knock off electrons, ionizing the atoms. An electric field then will accelerate both the xenon ions and electrons and expel them from the craft. The thrust will be anemic — amounting to little more than the weight of a quarter held in your hand. But the ion engine will provide a continuous acceleration that will build up significant velocity over time.

NASA's newly developed Orion spacecraft (right), likely with a crew of two astronauts aboard, approaches the robotic asteroid-capture vehicle and its wrapped cargo. NASA



The Orion spacecraft (left) starts to dock with the capture vehicle. The Orion capsule and its crew will take approximately five days to reach its quarry in lunar orbit. NASA

Bagging it

If all goes according to plan, the mission will get underway in 2017. Following liftoff from Florida's Kennedy Space Center, an Atlas V booster will propel the 20-ton asteroid-retrieval spacecraft into low Earth orbit. Then, under the weak but continuous thrust of its ion engines, the tug will embark on a long spiral path out of Earth's gravitational field. The solar panels will take a beating, losing 20 percent of their efficiency from the effects of radiation in the Van Allen belts that surround Earth. It will take nearly 700 days for the ship to cruise to the NEA along a sweeping solar orbit that will carry the probe halfway around the Sun.

Upon rendezvous, the spacecraft's largely autonomous onboard computers will have to deal with a tumbling target. After a series of careful maneuvers, the nimble spacecraft will match its rotation with the asteroid's spin axis. The craft then will inflate and deploy its huge capture bag and cinch it around the asteroid. The two objects will continue to tumble in a space waltz until the tug's thrusters bleed off momentum and the asteroid stops spinning.

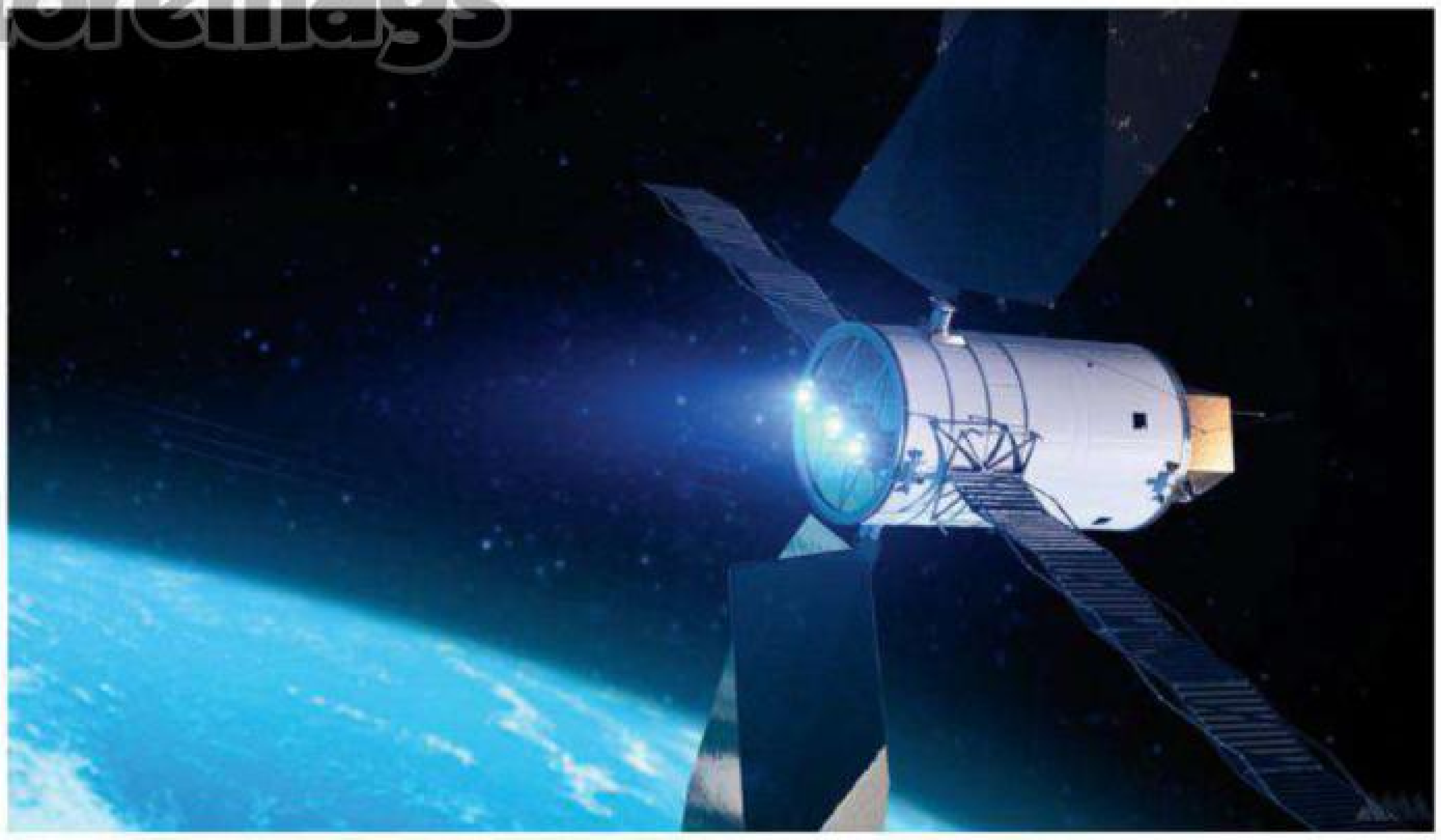
The asteroid-spacecraft bundle will need about 1,000 days to cruise through interplanetary space to reach Earth's neighborhood. Mission controllers will send it on a trajectory that allows the Moon's gravity to capture it. It then will take another 250 days to modify the pair's course and place it into an orbit some 38,000 miles (61,000 kilometers) above the lunar surface that would remain stable for 100 years.

The asteroid will shuttle between the first and second Lagrangian points of the Earth-Moon system, two stable nodes where the gravity of the Moon balances that of Earth. The first point lies between the two worlds while the second lies beyond the Moon from Earth's perspective. After all, lunar orbit is a safer place to park an asteroid than Earth orbit — just imagine filing an environmental impact statement for the Earth option!

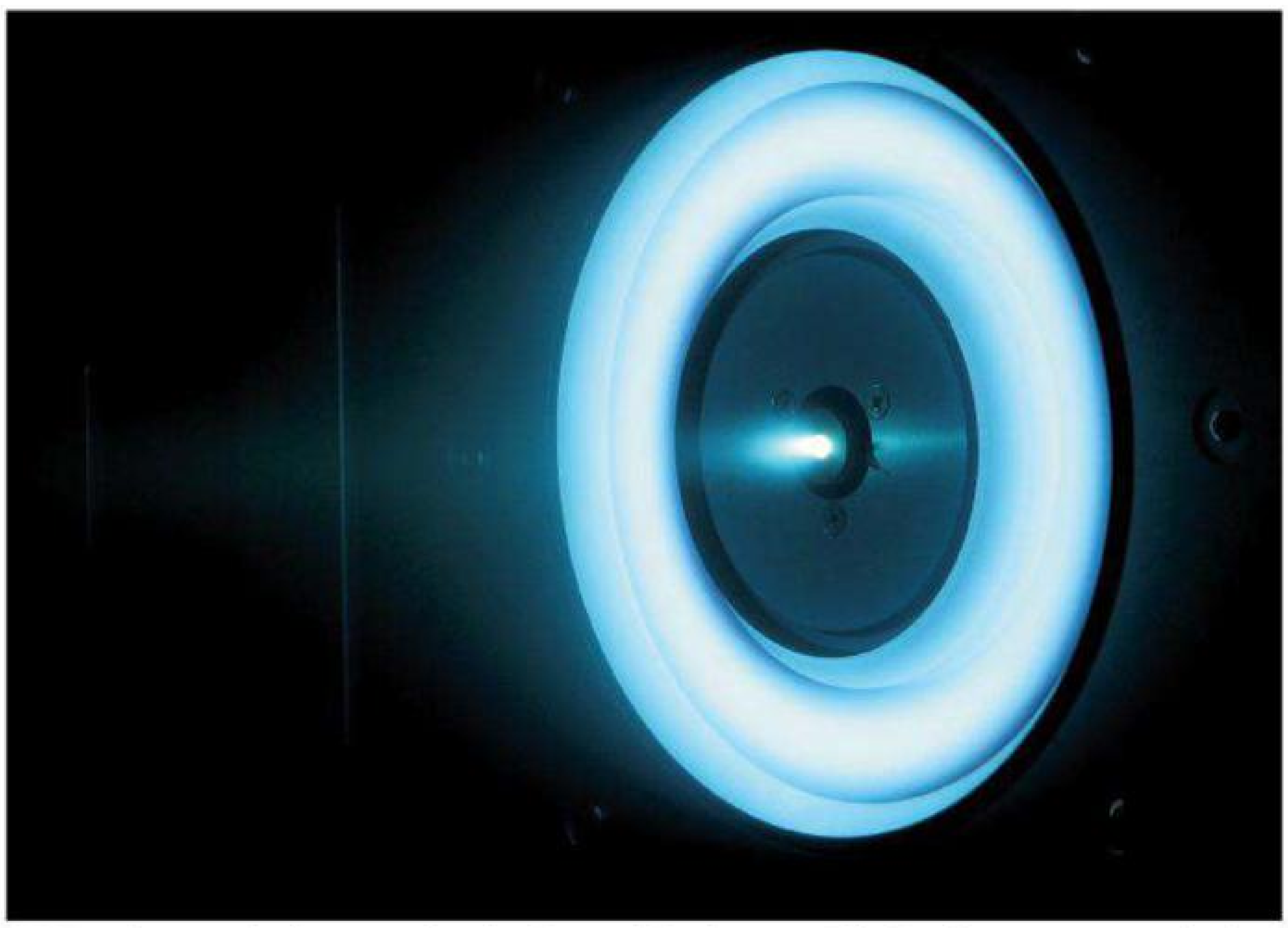
Rock collecting

Once the asteroid reaches its final orbit, NASA will launch a manned Orion capsule toward a rendezvous. The outbound leg will take five days. The Orion crew will maneuver their capsule carefully and sidle up to the spin-stabilized asteroid-capture vehicle. The astronauts then will use a grappling arm to dock with the other craft, in much

The ion engine will provide a continuous acceleration that will build up significant velocity over time.



A key piece of technology required for the asteroid-capture mission is solar-electric propulsion. In this concept, the robotic spacecraft has three thrusters that fire nearly continuously. ANALYTICAL MECHANICS ASSOCIATES



NASA continues to develop new solar-electric propulsion thrusters. This view shows xenon atoms jetting from a prototype ion engine at the Jet Propulsion Laboratory in Pasadena, California. NASA/JPL-CALTECH

the same way that shuttle astronauts snagged the Hubble Space Telescope for servicing.

Because Orion will have no air lock, the entire capsule will need to be depressurized for the space-suited crew to leave the vehicle and spacewalk to the asteroid. This will restrict the first mission to two extravehicular activities over a five-day period, with a day of rest between.

Astronauts will set up a pole between their Orion capsule and the docked vehicle and use it to make their way over to the space tug. This vehicle, which will have railings that the astronauts can climb along to reach the asteroid, will serve as their space platform. Two astronauts will anchor their feet to a servicing platform at the end of a long boom and then be positioned alongside the asteroid.

Because the asteroid presents a significant dust hazard, it will remain bagged in lunar orbit. Like a kid peeking at a wrapped Christmas present, the astronaut team will peel back part of the envelope encasing the rock. The two spacewalkers will snap hundreds if not thousands of digital photos and transmit them to Earth.

For the first time in history, a human hand will touch a pristine deep-space relic that predates Earth's formation. What might he or she say? "That's one small grab for a human, one giant reach for mankind"?

The astronauts will return to work quickly, using a variety of hand tools to chip away at the asteroid's surface. They dutifully will seal and label samples for return to Earth. Once the 4.5-billion-year-old rocks are on our home planet, scientists at the Lunar and Planetary Laboratory at NASA's Johnson Space Center in Houston will analyze them.

Based on that research, NASA will develop plans for a second mission to the asteroid and more detailed sample collection. The space agency sees this initial visit largely as a way to test the logistics of operating near a small body in space and the methods that one day could lead to mining an asteroid and processing its material.

Once NASA finishes its study of the asteroid, the agency could send the space boulder onto a collision course with the Moon. Even if things went haywire and the asteroid accidentally fell toward Earth, it would be so small that it would disintegrate in the atmosphere — although that assurance might not mollify doomsayers.

Asteroid science

The astronauts might bring the material they collect to the International Space Station, where crew members could process some material in a microgravity environment. Whether in space or on the ground, scientists will analyze the samples thoroughly to learn what role asteroids might play in the future exploration of space.

A single 20-foot-wide (6m) asteroid could deliver a long shopping list of space resources: 200 tons of silicates, 100 tons of water, 100 tons of carbon compounds, and 90 tons of metals — mostly iron, nickel, and cobalt. The water alone could be worth its weight in gold. Solar power could be used to split water into hydrogen and oxygen, which could serve as rocket fuel. The oxygen also could provide humans with breathable air.

The rest of the extracted material could be used to build, supply, and shield from radiation a manned deep-space mission or an outpost at the second Lagrangian point of the Earth-Moon system.

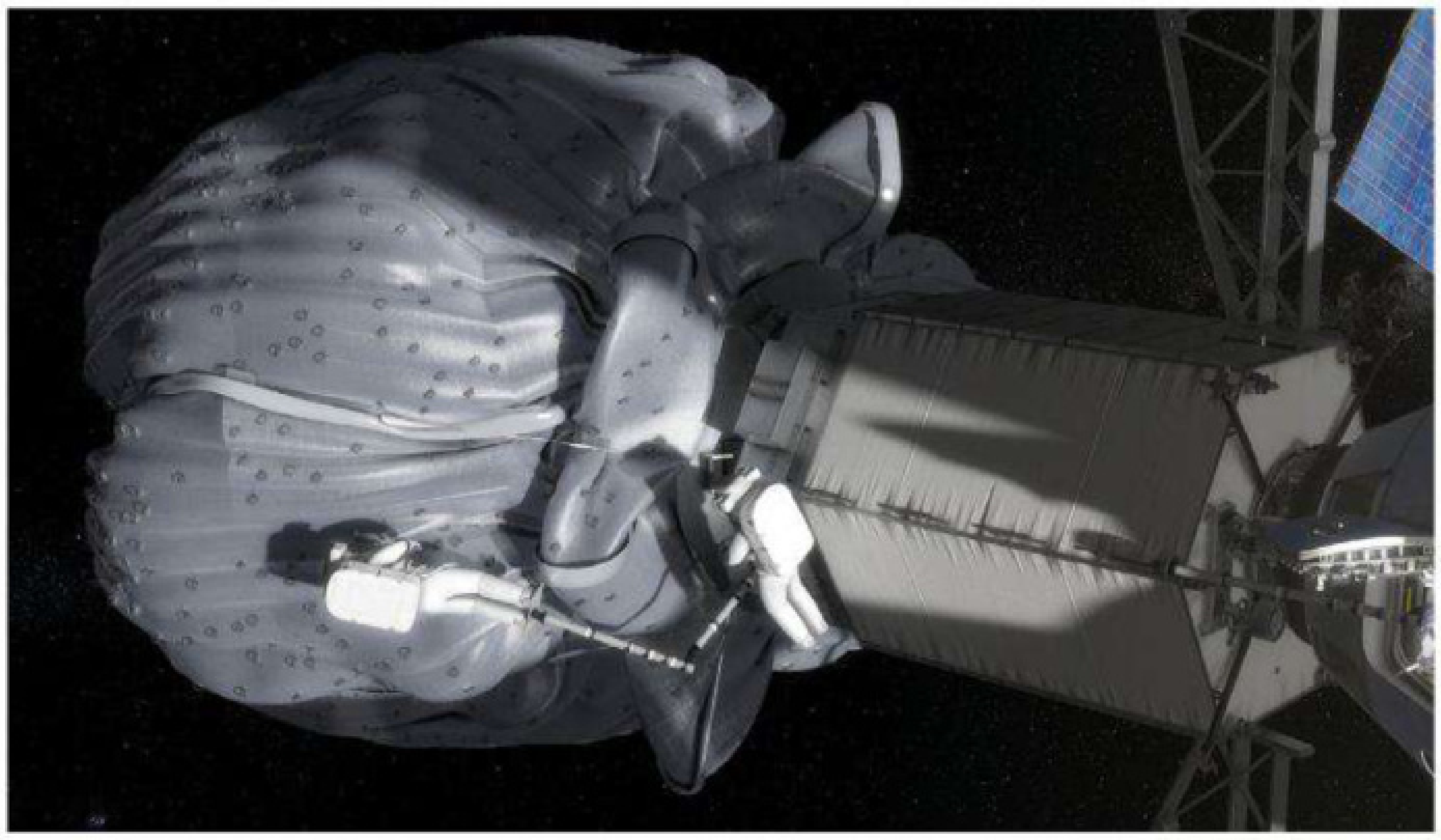
"That's one small grab for a human, one giant reach for mankind."

What makes this approach so attractive is that a mission to an asteroid would make 28 times as much mass available for building space habitats as the mass required to launch the initial space tug. This so-called mass amplification is unprecedented in current space exploration. To lift something into Earth orbit or beyond requires overcoming our planet's strong gravitational pull. This demands a launch vehicle that carries more weight in fuel than in cargo. That's why today's launch costs are so staggering: $10,000 per pound of payload weight. Launching the equivalent of a small asteroid's bulk off Earth's surface would blow the budget at $20 billion.

If the asteroid-snagging experiment proves successful, you could imagine a freight train of robotic probes continually hauling raw asteroid material back to the Earth-Moon system at an estimated cost of "only" $1 billion per mission.

NASA's proposed mission also could help scientists improve the strategies for defending Earth from wayward asteroids. For example, experiments could show the best ways to attach a robot to an asteroid. At the most basic level, this could serve as practice for implanting a transmitter in an asteroid to precisely track it. Scientists also might use a robot to anchor a rocket engine to an asteroid and provide thrust to deflect it away from Earth.

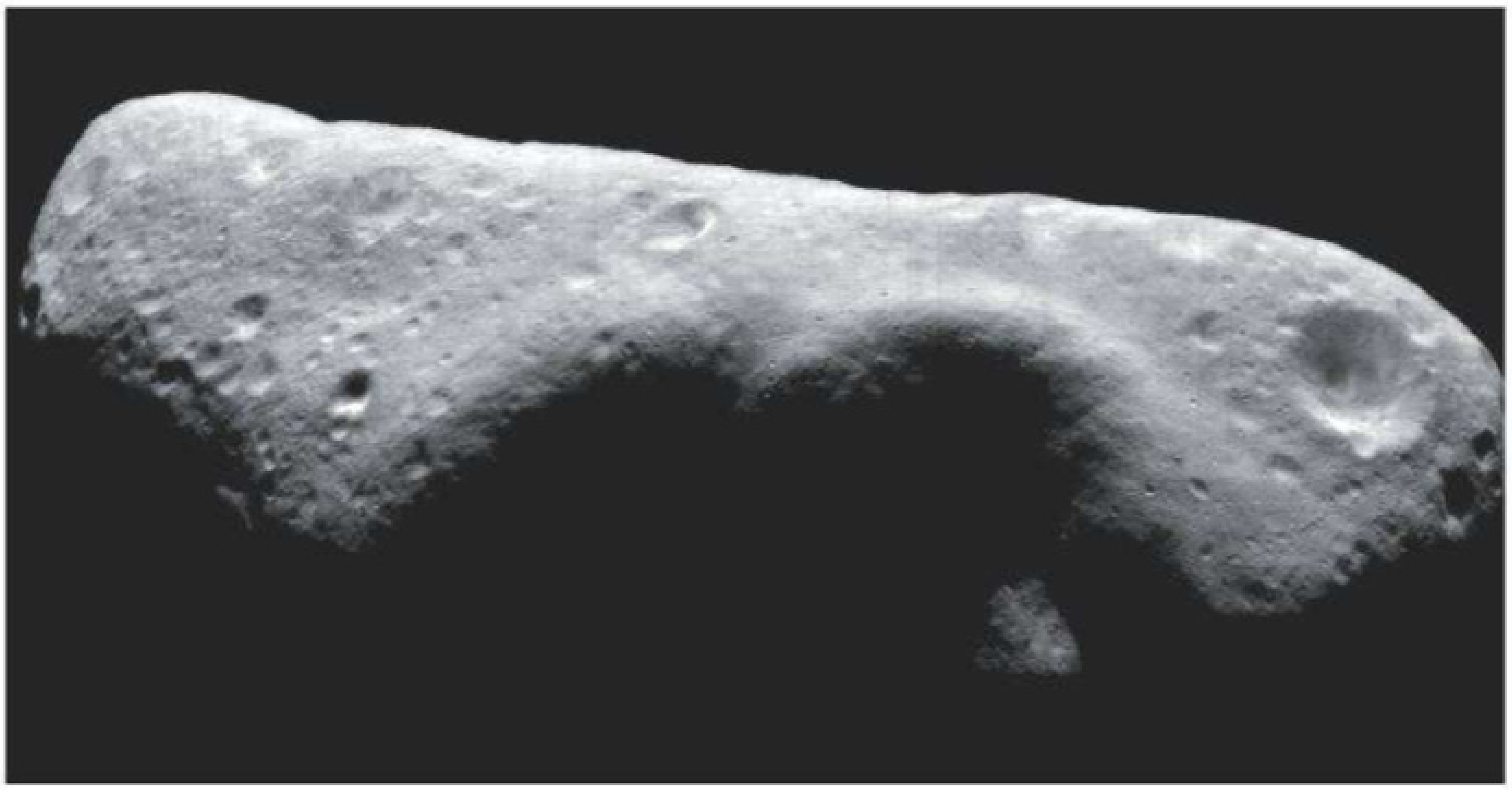
Another deflection technique calls for hitting an asteroid with a projectile to change its course. Yet scientists have only educated guesses as to how much momentum such a missile could transfer to the asteroid. A captured asteroid in lunar orbit could serve as a target for such impact experiments. Ultimately, scientists might decide to embed a nuclear device inside the asteroid. NASA then would refuel the transfer vehicle, tow the asteroid back into an orbit around the Sun, and blow the rock to smithereens. We'd witness firsthand what it would take to demolish an Earth-threatening asteroid.



Two astronauts embark on a historic spacewalk, working their way along a pole that connects their Orion capsule (right) with the captured asteroid. NASA

After peeling back the covering, an astronaut retrieves a sample from the captured asteroid. NASA

After collecting an asteroid sample, an astronaut stores it for its return to Earth. NASA



The NEAR-Shoemaker spacecraft took this mosaic of the near-Earth asteroid Eros during its mission in 2000. Although Eros is far larger than the asteroid NASA plans to capture and tow, scientists would learn plenty by getting their hands on pieces of the smaller object. NASA/JPL/JHUAPL

Highway or byway?

As daunting as the asteroid-retrieval mission might seem, some planetary astronomers see it as a distraction. They think it could crowd out further Mars exploration or sorties to the intriguing moons of the outer solar system. A National Research Council report from a year ago concluded that a human asteroid mission does not have as much public support as a return mission to the Moon.

Nevertheless, the Keck Institute for Space Studies report heralds the asteroid mission as a steppingstone between human presence on the International Space Station in low Earth orbit and deep-space exploration. The authors concluded: "Placing a 500-ton asteroid in high lunar orbit would provide a unique, meaningful, and affordable destination for astronaut crews in the next decade. This … capability would have a positive impact on a wide range of the nation's human space exploration interests. … NASA would be putting human explorers in contact with an ancient, scientifically intriguing, and economically valuable body beyond the Moon."

TO SEE A VIDEO DEPICTING THE PROPOSED ASTEROID-RETRIEVAL MISSION, VISIT **www.Astronomy.com/toc.**

The weird world of PHOEBE

Scientists are finding that Saturn's strange moon isn't like the other satellites in the solar system. **by Michael Carroll**

Phoebe is an oddball moon of Saturn. Even though it's small, it has a spherical shape and other planet-like characteristics. Scientists think volatiles breaking through the surface in Phoebe's early history (as illustrated here) might be responsible for its rounded shape and craters. MICHAEL CARROLL FOR *ASTRONOMY*

Planetary evolution seemed so straightforward. The process began, so the story went, with a disk of dust and gas called the solar nebula. At the center of this rotating disk, a dense clump condensed and became a star — the Sun. It pulled in more material while its gravity grew. And just as an ice skater pulls her arms in to spin faster, the disk's rotation speed began to increase.

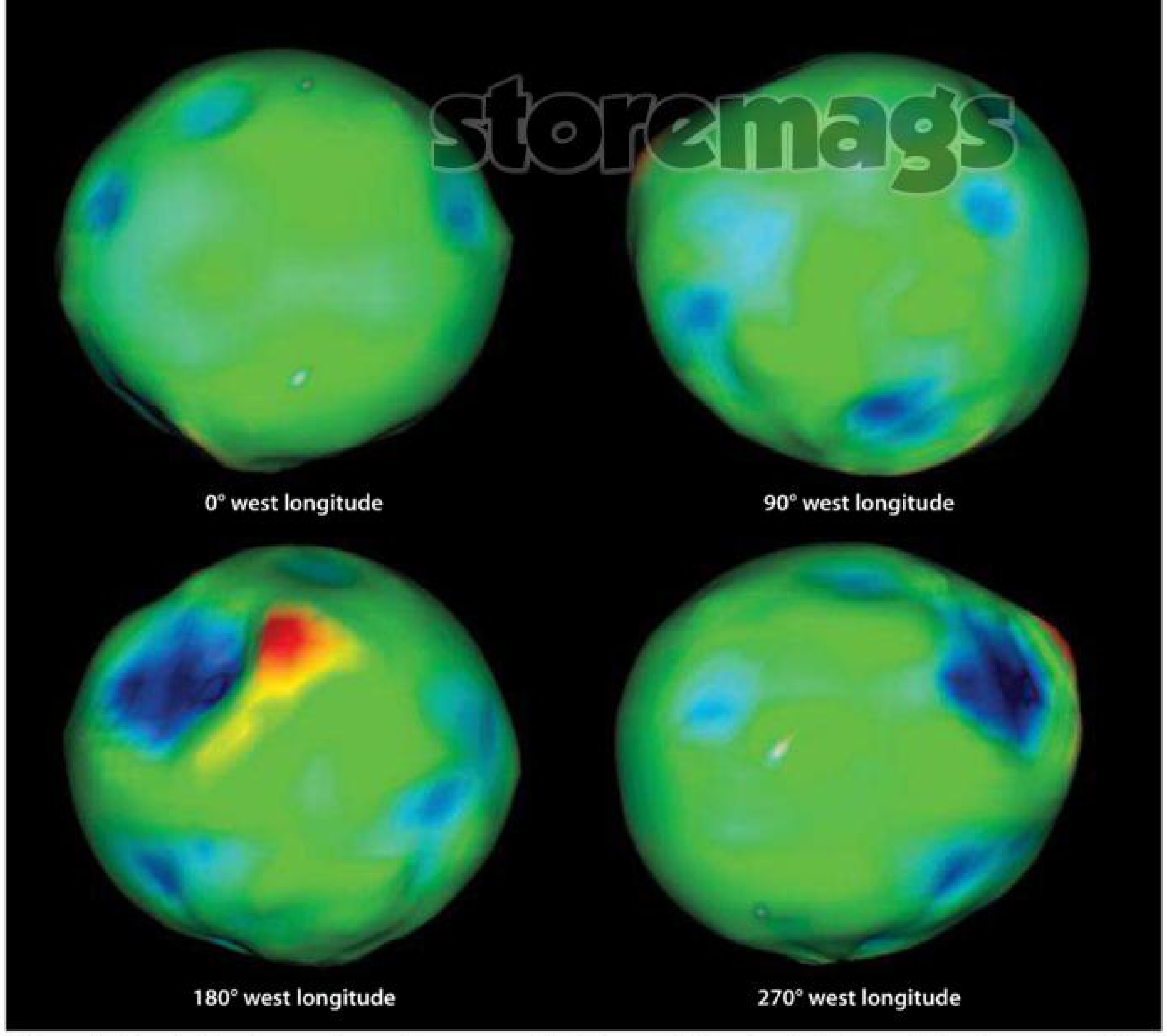
Irregular clumps of gas and dust that moved throughout the disk grew into asteroids, comet nuclei, and, ultimately, planets. The rocky terrestrial planets — Mercury, Venus, Earth, and Mars — established themselves near the Sun; the infant star's heat burned away many of their volatiles (elements and compounds with low boiling points). Out where it was colder and calmer, the bodies that would become Jupiter and Saturn pulled hydrogen and helium toward themselves from the surrounding solar nebula. Farther out still, Uranus and Neptune were able to hold onto water and eventually became the ice giants we see today.

The interiors of the planets and the solar system's largest moons seemed predictable, too: Due to a phenomenon called differentiation, heavy elements within such a world sank to become a core while lighter ones rose to form a less dense crust. The smaller bodies, the ones with less mass and thus lower gravities like comet nuclei and smaller moons, carried out no such settling and retained their well-mixed interiors.

Scientists have long considered this scenario their standard model. Then came Saturn's moon Phoebe.

Surprisingly spherical

As natural satellites go, Phoebe, with a diameter of 132 miles (213 kilometers), falls below the midrange size of more familiar moons like Iapetus or Mimas. This number is significant: Other satellites of similar sizes are not large enough for their weak gravities to pull them into spherical shapes. They are probably cold clumps of rock and ice. Not so with Phoebe. The strange moon is round, leading scientists to hypothesize that internal heat may



Although Phoebe has bumpy, irregular topography, it has a fairly spherical shape. Scientists created this digitally rendered model of Phoebe's shape using imaging data taken when NASA's Cassini spacecraft flew by the saturnian satellite June 11, 2004. NASA/JPL/SPACE SCIENCE INSTITUTE

GEORGE GRANTHAM BAIN COLLECTION (LIBRARY OF CONGRESS)

William Henry Pickering discovered Phoebe — Saturn's ninth satellite — in 1899 after studying photographs he took in August 1898.

have softened it early in its history. Phoebe's density is also higher than typical icy saturnian satellites. Both of these pieces of information suggest that the tiny satellite may be differentiated with a dense rocky core, putting it in the small club of planet-like bodies. "It's very different from the rest of the saturnian system," says planetary scientist Julie Castillo-Rogez of the Jet Propulsion Laboratory (JPL) in Pasadena, California.

Researchers can learn about a solar system object's interior and thus if it is differentiated using spacecraft flybys. Such a world is much more massive than any probe, so when a craft passes by a planetary body, the massive object's gravity bends its course. Flight engineers can chart this path. If the pass is close enough to the planet or moon or if there are enough passes, scientists can determine the larger object's internal structure. While researchers have used data from NASA's Cassini spacecraft to employ this method to learn about Enceladus and Titan, the probe did not fly close enough to Phoebe to permit such estimates, Castillo-Rogez says. The calculation has "a huge error bar," she continues. "But the one thing that is robust is that the shape of Phoebe is close to equilibrium; it had to be partially molten for this to happen."

When a planet settles, or relaxes, into a spheroid, it reaches gravitational equilibrium — its shape is stable under the influence of its internal gravity. Phoebe seems to have reached this point. If it has, says Castillo-Rogez, its core likely heated the outer layers to give the moon its shape. "Phoebe should be like [saturnian satellite] Hyperion, with lots of porosity throughout," she adds. "The fact that it has a high density — three times greater than Hyperion — tells us that something happened to cause the collapse of the porous [outer layers]. The most likely idea is that it got warmed up so the [surface] ice could melt and flow. The shape is globally relaxed. That's the most important observation, and it comes from analyzing photos from many angles."

But smaller bodies hold heat for less time. Where could Phoebe's heat have come from? Bonnie Buratti of JPL suggests one scenario: "Phoebe may have formed very early in the solar system, when there were isotopes with a short life." As radioactive isotopes decay, they lose radiation and/or particles and release heat. For any given amount of such radioactive material, the time it takes for half of the mass to decay is called its half-life.

One isotope that may be responsible for Phoebe's heat specifically, Buratti says, is aluminum-26, which has a half-life of about 720,000 years. "It produces a lot of heat in a few thousand years," she says. "That heat may have been responsible for hydrothermal activity and other processes. Small bodies with very rich chemistry were heated by these isotopes with short half-lives. [The objects] need to form very early for that heat to be available. Formation within the first 3 million years [of the solar system] gives us a way to relax Phoebe's shape."

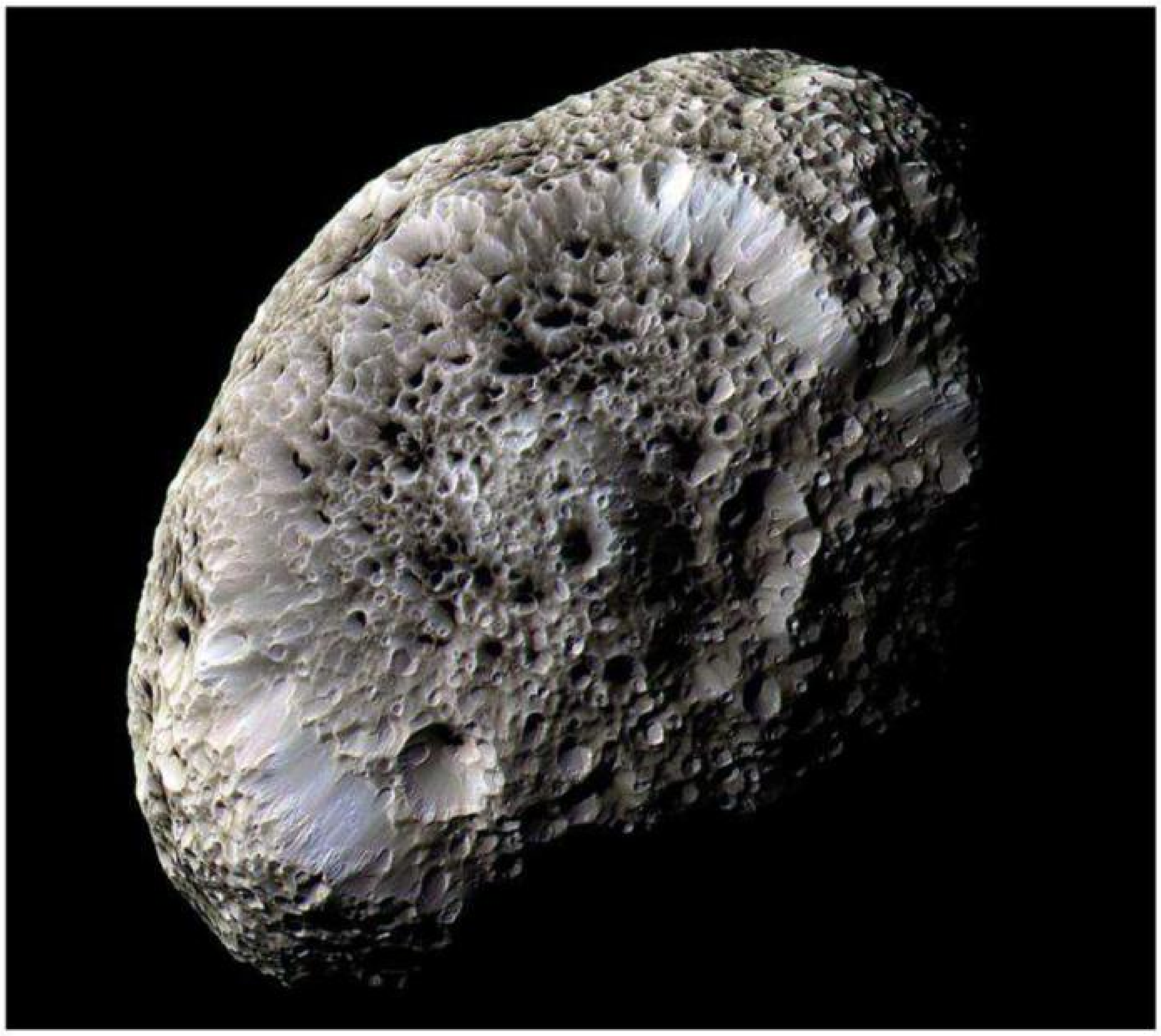
From outside or within?

That relaxed surface also affects the shape of craters. Phoebe's crater rims seem to be composed of only ice in certain places, and the craters themselves are oddly shaped. "If you look at the craters on Phoebe, they don't look like impact craters," says Buratti. Instead, to scientists they appear to result from internal forces, such as gas or volatiles escaping

NASA/JPL/SPACE SCIENCE INSTITUTE

The crater at top center displays alternating layers of bright and dark material. Researchers think its appearance might be the result of subsurface light-colored icy material thrown out (perhaps from internal venting) that buried the darker surface layer. Based on this and similar evidence, scientists think Phoebe has a dusty surface covering an icy interior.

Michael Carroll, *a science writer and astronomical artist, won the Jonathan Eberhart Planetary Sciences Journalism Award for his August 2011* Astronomy *article, "Storm warning."*



Saturn's moon Hyperion has a low density, giving it weak surface gravity and high porosity. Scientists would expect Phoebe to have a similar appearance due to its comparable size; Hyperion is about 220 miles (360 kilometers) across its longest axis, while Phoebe is 132 miles (213km) wide. NASA/JPL/SPACE SCIENCE INSTITUTE

through the surface. According to Buratti, "Their shape could also be due to mass wasting where the sides have caved in. These craters are cone-shaped — very strange." Castillo-Rogez agrees, adding, "The largest crater has practically lost her head!"

Phoebe is not the only oddball in the saturnian system, and that's what makes its study so fascinating to researchers like Castillo-Rogez. "You have such a variety of bodies, and they probably don't come from the same place," she says. "We think the inner satellites formed from the rings of Saturn. Hyperion may be a fragment of another [inner] body or a captured object. Iapetus may be original to the system, but its density is very weird. Then you have Phoebe and other outer satellites that are probably captured."

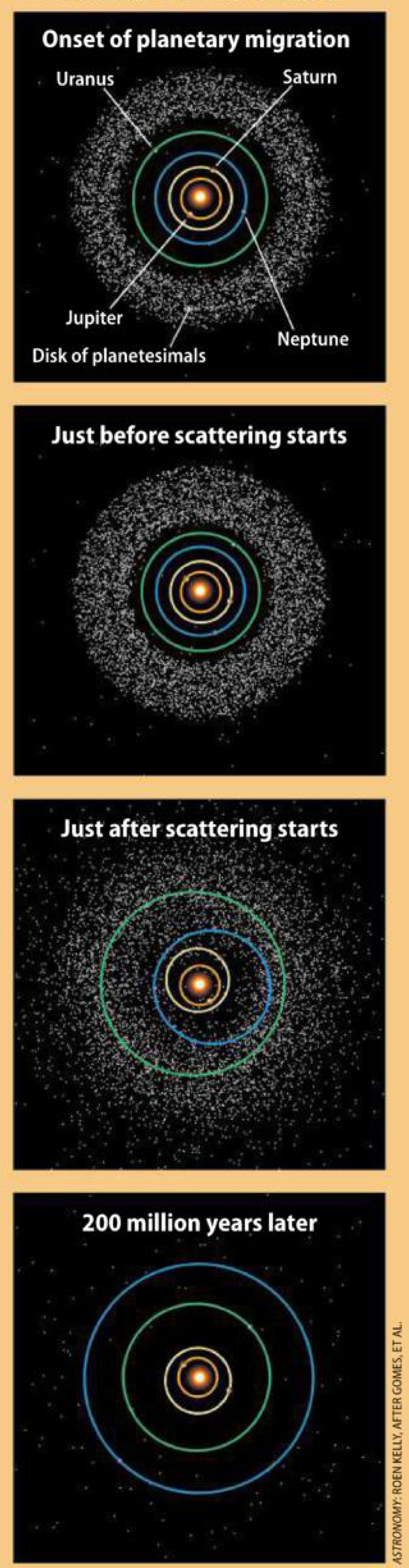
Phoebe's orbit provides a hint that it winged its way in from afar: The moon circles Saturn in a retrograde course, opposite the direction that the saturnian system naturally rotates. Its orbit is also eccentric — not circular — and inclined at an extreme angle. Phoebe travels far from its parent world, circling the planet in a great loop some 16 million miles (26 million km) across. These clues point to a capture of the moon early in the evolution of our solar system.

If Phoebe came from somewhere other than the saturnian system, its early wanderings reinforce the chinks in the standard model's armor. Many researchers believed something might be awry with their theory long before they got a close look at Phoebe, says Hal Levison of the Southwest Research Institute in Boulder, Colorado. In its formative years, he explains, "the Sun shed angular momentum by creating a disk of material. Grains of ice and rock were floating around in the disk." Those particles slowly settled, stuck together, and thus grew into larger objects: the solar system's four terrestrial planets, Uranus, Neptune, and what scientists think are the cores of Jupiter and Saturn. But, in the standard model, those bodies formed where they currently orbit. The problem, says Levison, is that this depiction simply cannot be true.

Was upheaval needed?

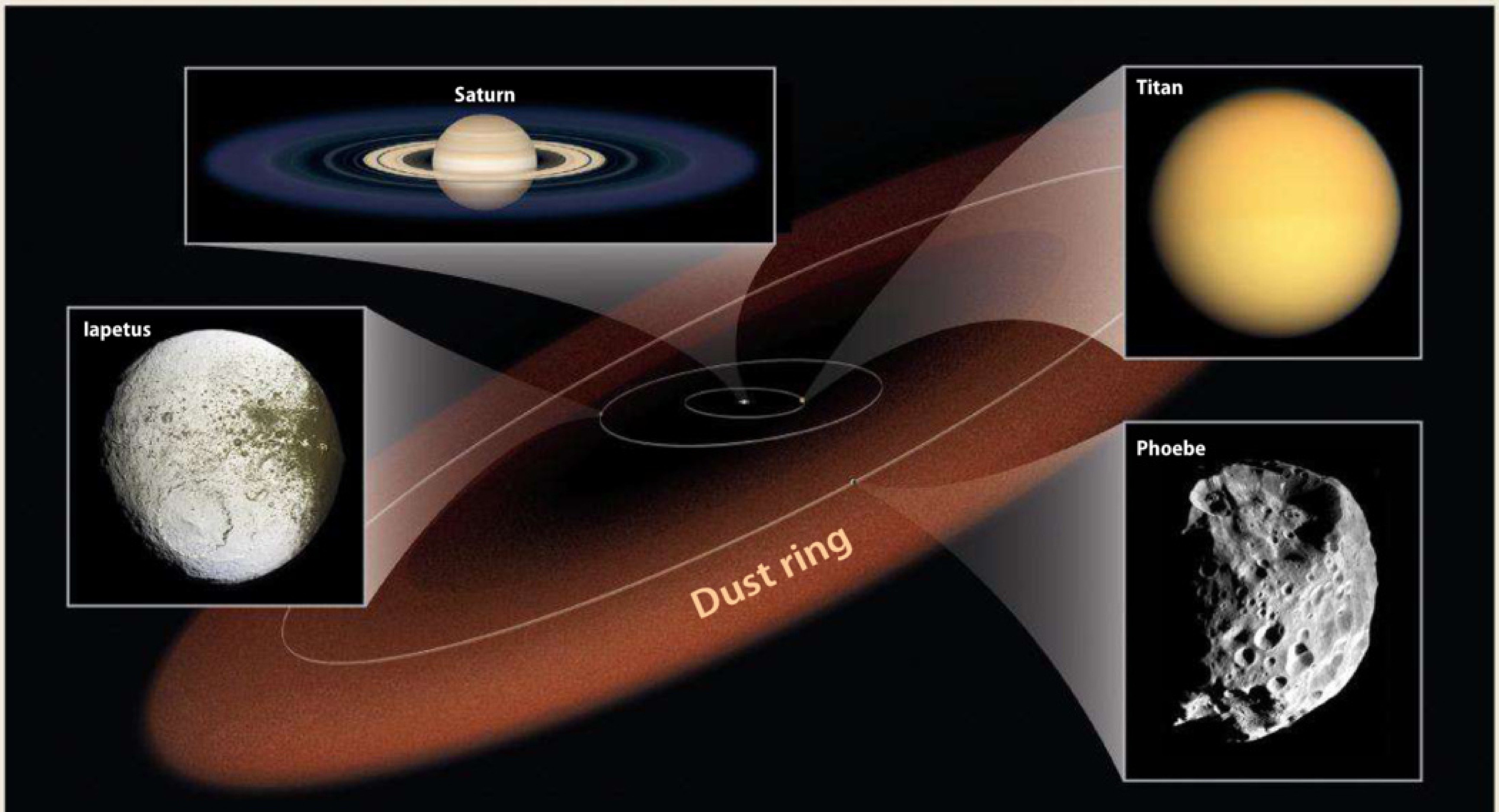
The standard model of planet formation faces two major problems. The first is what Levison calls the meter barrier. "Imagine these floating dust grains," he says. "These stick together and grow like dust bunnies. In objects 1 to 10 kilometer-size [0.6 to 6 miles], if they hit gently enough, they'll stick because of gravity." But scientists

The Nice model



The Nice model is scientists' leading theory of the early solar system's evolution. It maintains that around 4 billion years ago, Jupiter's and Saturn's orbits passed through a resonance, flinging Uranus and Neptune farther out and into a disk of protoplanetary bodies. The upheaval might have thrown Phoebe inward, where Saturn's gravity held onto it.

PHOEBE FEEDS SATURN'S MOST DISTANT RING



In 2009, scientists discovered a new ring around Saturn that they think is fed by dust from Phoebe. This ring is the largest yet known in the solar system.

ASTRONOMY: ROEN KELLY; NASA/JPL/SPACE SCIENCE INSTITUTE (IAPETUS; PHOEBE; SATURN; TITAN)

While astronomers have known about Saturn's characteristic bright ring system for centuries, they identified an enormous dust ring around the planet in 2009. Phoebe orbits within the ring, so astronomers think the moon contributes material to it. This is the largest known planetary ring in the solar system.

Using NASA's Spitzer Space Telescope to detect infrared radiation, Anne Verbiscer of the University of Virginia in Charlottesville and colleagues found the thick ring. Its inner edge starts around 4.8 million miles (7.7 million kilometers) from Saturn and extends to 7.8 million miles (12.5 million km). It's some 40 times as thick as the planet's radius, which matches Phoebe's vertical motion along its orbit. The ring seems to be inclined 27° to Saturn's equatorial plane; the moon's orbit follows a 30° angle to the planet's plane.

The newly discovered ring is about 100 times larger than the planet's main ring system. That system is also aligned with Saturn, which means a different mechanism must have helped form this newly found ring. Scientists think particle impacts with Phoebe produced debris that remains in a thick disk around the satellite's orbit, creating this huge ring. — *Liz Kruesi*

have a problem with the bodies between dust-grain-sized and kilometer-sized. Levison points to two coffee mugs on his desk. "If I bring these two cups together, no matter how gently, they aren't going to stick together," he says. "There is no good force to hold together things that are a meter- to a decimeter-size. Another problem is that there is aerodynamic drag on the particles. They are feeling the force of the gas they are moving through — feeling the headwind."

Small particles (micron-sized) can be suspended in the gas of the primordial solar nebula without settling, while drag doesn't affect large bodies because of their mass. But those in-between objects, in the meter range, should migrate into the Sun before they grow, effectively preventing any planets from forming. "This has been a problem the field has faced since the '70s," Levison says.

Some researchers propose that turbulence in the solar nebula may have concentrated meter-sized objects in "eddies" — regions where fluid or gas flows differently from other nearby environments. The Sun's disk may have hosted swarms of boulder-sized rocks, herded into these vortices, which then gradually interacted to form larger objects.

A second substantial change in scientists' view of planetary evolution — and one that is better established — is that the giant planets did not form in their current orbits. "You cannot make Uranus and Neptune where they are," Levison declares — they must have formed nearer to the Sun. "The problem we find is that if you put a bunch of Earth-sized objects out in that region, they don't hit each other," he explains. "They gravitationally scatter one another into Jupiter-crossing orbits, and Jupiter throws them out of the solar system. You simply cannot get these guys to accrete [in the current Uranus-Neptune region]."

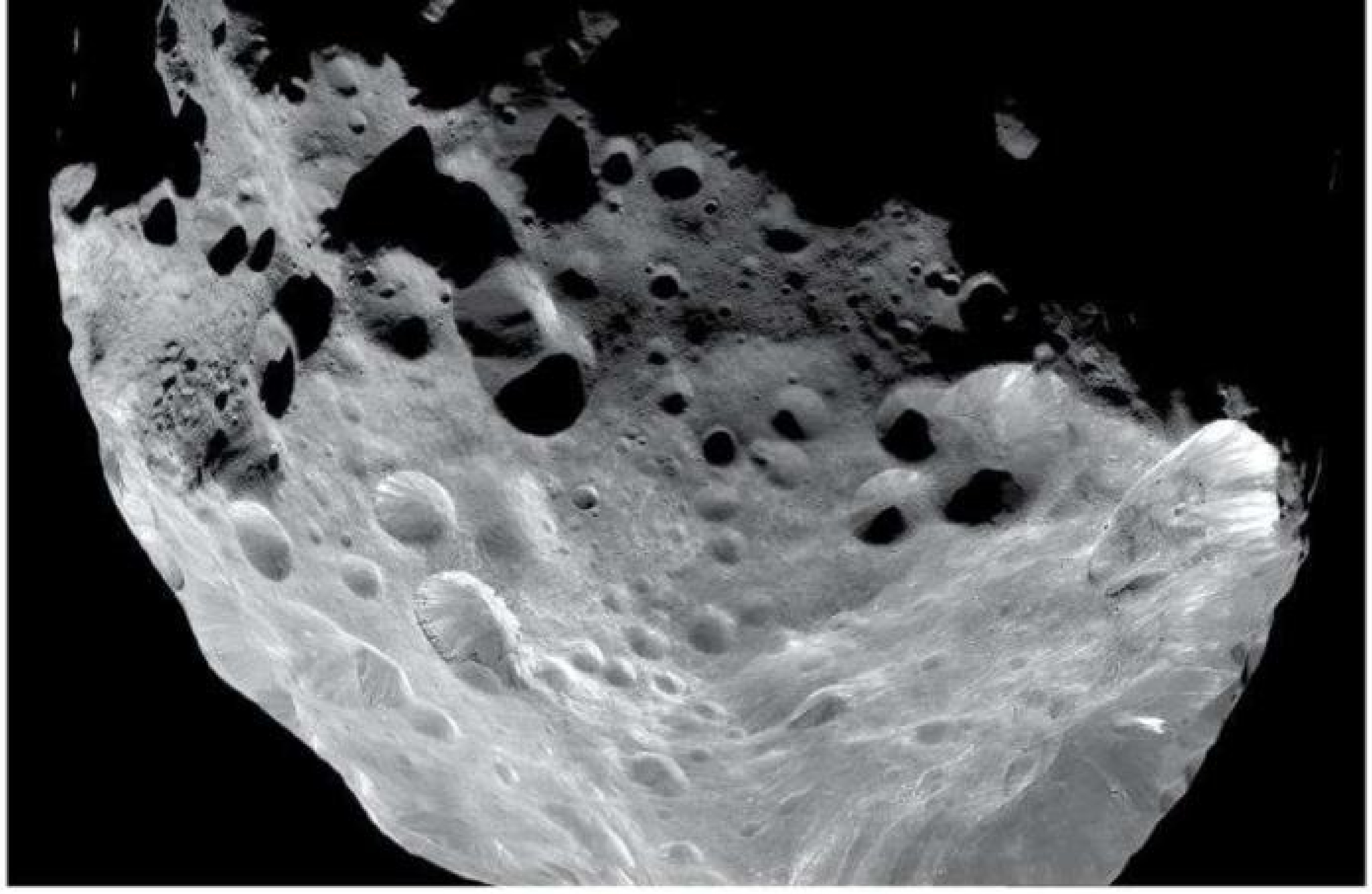
The Kuiper Belt of thousands of objects beyond Neptune poses another mystery. Beyond the eighth planet, bodies move with high inclinations and high eccentricities in resonances with Uranus and Neptune. (One example of such an object is Pluto, which completes two orbits for every three of Neptune — a 2:3 resonance.) But because of the way planets develop, these objects had to have formed in circular, low-inclination, low-velocity orbits. That's the only way to get planets to accrete, yet observers find quite a different picture in the Kuiper Belt.

"We see objects on inclined, high-eccentricity orbits," says Levison. "We see multiple populations that clearly came from different locations superimposed on each

other. It looks like somebody took the disk of material in the outer solar system and shook it real hard. The planets in their current configuration just can't do that." Something had to change in the structure of our planetary system. Dynamicists now suspect that the giant planets began in a compact configuration and then migrated out. This scenario is the heart of the Nice model, named after the town in France where Levison and three colleagues first combined forces to craft it (see illustration on p. 31).

The Nice model proposes two extreme alternatives to the standard model. One of these scenarios describes a smooth migration where Uranus and Neptune slowly spiral out through the solar nebula. The other idea maintains that the four giant planets (and possibly a fifth, which was later ejected from our solar system) huddled much nearer to the Sun until a global instability caused Uranus and Neptune to take off in crazy trajectories. Their orbits crossed each other's and even intersected those of Jupiter and Saturn. Gravity from the two gas giants sent Uranus and Neptune packing, where they settled into a disk of planetesimals that no longer exists. This population of outer asteroids and comet nuclei, which would eventually give rise to the Kuiper Belt, was "a place where thousands of Earth-like masses allowed things like Pluto and Phoebe to grow," says Levison.

The giant planets later destroyed the disk, but its mass and interaction with the worlds closer to the Sun essentially saved the giant planets, preventing them from being ejected from the solar system. Not everybody accepts the Nice model, but, Levison asserts, "No one has developed a model that is even close to being an alternative."



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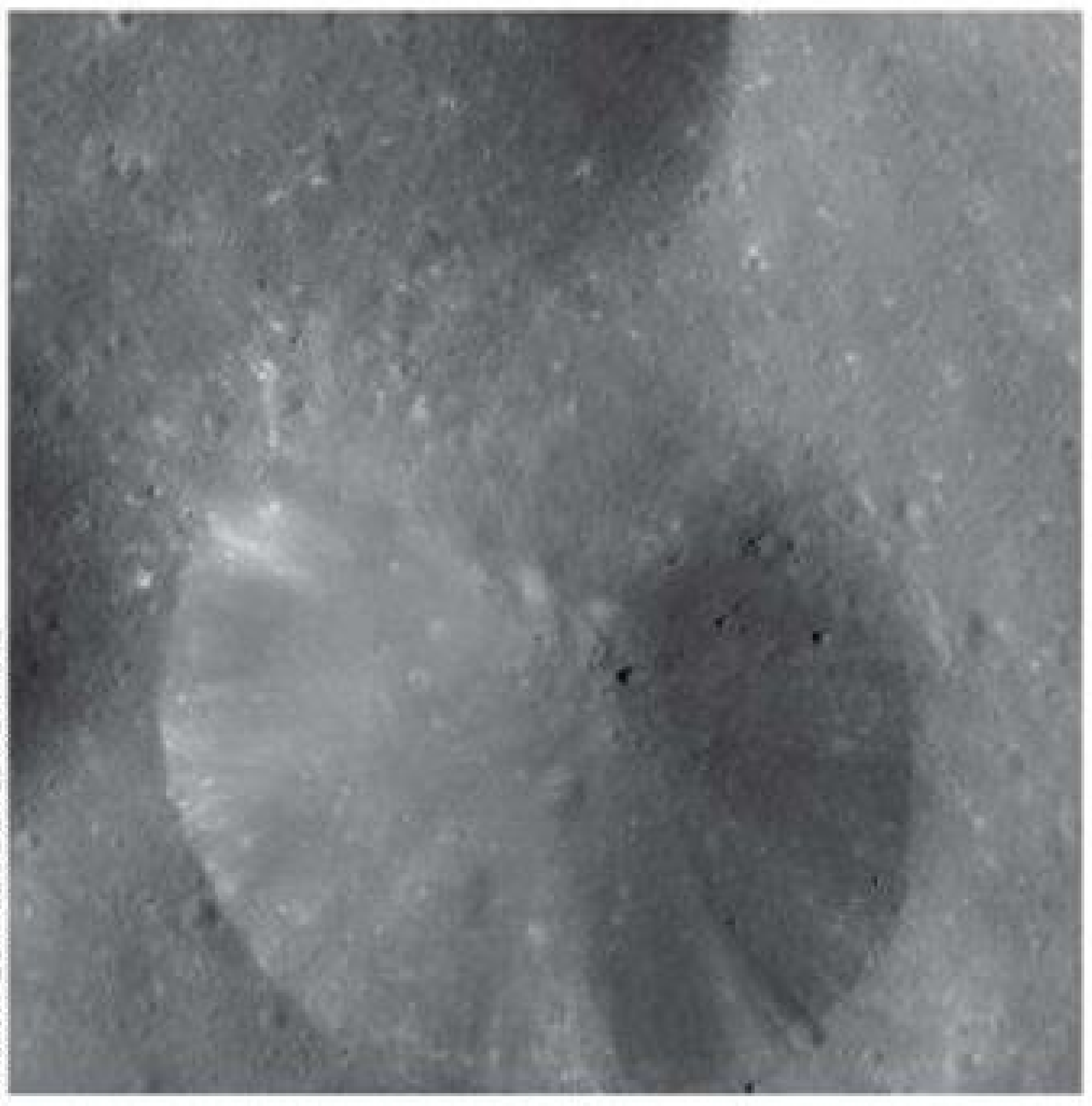
The Cassini spacecraft captured high-resolution photographs of Phoebe during a 2004 flyby, and scientists combined six to create this mosaic. This image shows detail as small as 243 feet (74 meters) wide.



NASA/JPL/SPACE SCIENCE INSTITUTE

As loose fragments of ejecta run down the side of this crater on Phoebe's surface, they create streaks. The crater is 8 miles (13 kilometers) wide.

A captured interloper

The violent past that Levison and others point to may have left fingerprints on Phoebe's surface. Thanks to Cassini's spectrometer, an instrument that breaks a target's radiation into its constituent wavelengths, Buratti and colleagues see carbon-dioxide ice. "If you look at the visible spectrum, there's a kind of upturn toward the ultraviolet [that may be] due to scattering from iron particles," she says. "There's also a contending theory that the surfaces are covered with organic molecules — polycyclic aromatic hydrocarbons." These hydrocarbons contain hydrogen, oxygen, nitrogen, and carbon — the building blocks of life.

Asteroids and meteoroids known as carbonaceous chondrites form in the outer portion of the solar system's main asteroid belt or beyond, where the environment is cool enough for complex hydrocarbons to form. "There are these wet, hydrocarbon-filled objects that appear in the main belt, and some get transported into the inner system," says Buratti. While Phoebe's surface shows a history of impactors — that likely originated from the main asteroid belt — Buratti believes that observations of specific materials on the moon's surface might provide some evidence that it migrated in from an outer region, like the Kuiper Belt.

Cassini's instruments have detected volatiles that could indicate just that. Phoebe's organic surface composition is unlike any surface yet observed within Neptune's orbit. Its complex makeup causes Castillo-Rogez to wonder, "What happens when you take a Kuiper Belt object and bring it closer to the Sun?" She adds: "Phoebe has probably lost a lot of volatiles. When it formed, it probably had methane and nitrogen ice." Theory says that the moon lost those volatiles as it was flung from the outer depths of the solar system.

For Phoebe to have ended up where it is, its travels from the Kuiper Belt may have taken it closer to the Sun, perhaps as close as Jupiter, before capture. Once in Saturn's vicinity, there may have been even more fireworks: Phoebe may have had a sister.

Levison puts it this way: "There is no way that you could just have Saturn sitting there and have Phoebe come in by itself and become captured. Gravity is time-reversible. If something can get in, something can get out." In other words, for Saturn to capture Phoebe, a third object was necessary. In the encounter, Phoebe's companion would have been ejected and the lost energy would have slowed Phoebe enough for capture.

Another intriguing possibility is that Phoebe was a moon of either Uranus or Neptune. In those wild days of planetary migration, one of the ice giants may have come close enough to Saturn to shed some of its own natural satellites, perhaps actually trading a few with the larger planet.

Wherever Phoebe came from, its characteristics continue to intrigue. With its cone-shaped craters, rich mineralogy, spherical shape, high density and perhaps great age, Phoebe seems more planet than moon. And yet this bizarre little world ranks small in the solar system's retinue of satellites. Says Castillo-Rogez, "I like the smaller bodies of the solar system. They don't get the public excitement that Titan or Europa do, but they have their own story to tell."

LEARN ABOUT SATURN'S BIGGEST MOON, TITAN, AT **www.Astronomy.com/toc.**

ASK**ASTRO** *Astronomy*'s experts from around the globe answer your cosmic questions.

EXTREME SPIN

Q: WHAT DOES "BLACK HOLE SPIN" MEAN, AND HOW DO ASTRONOMERS MEASURE IT?

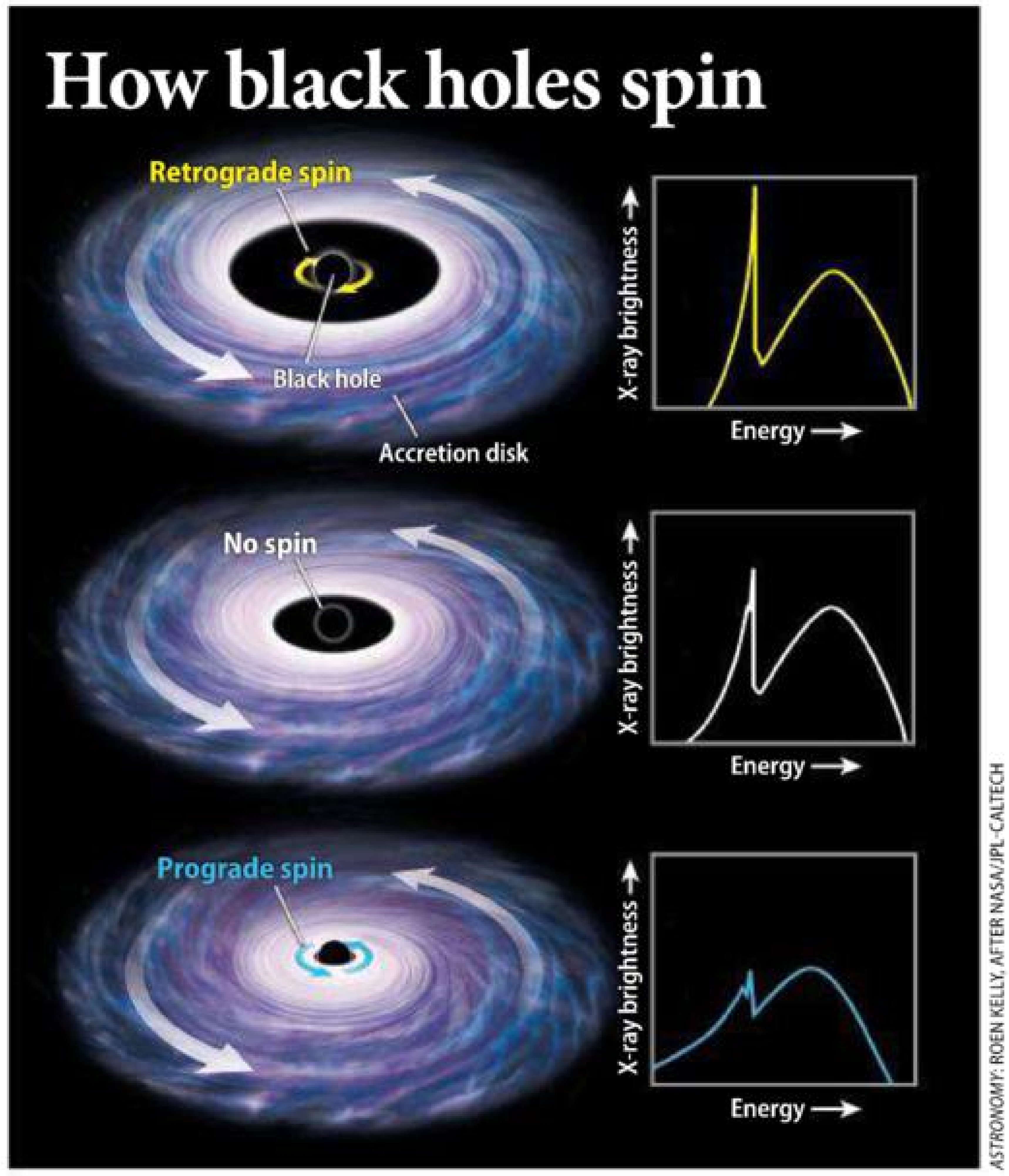
Stephen Smith, *Charlotte, North Carolina*

A: Like most objects in the universe (planets, stars, asteroids, and other compact objects), black holes rotate. We refer to this property as "spin" or, more formally, its "angular momentum" about its axis of rotation. This concept can be difficult to visualize because a black hole is not a solid body, but it helps if you start by imagining a black hole as the end product of a star's evolution. If a star begins its life with more than some critical mass (usually estimated at about 10 to 20 times the Sun's mass), it will ultimately end up as a black hole.

We think all stars spin, and thus so did the sun that collapsed into a remnant black hole. Like a figure skater that pulls her arms in and spins faster, the star's rate of rotation increases as the star itself gets smaller in radius due to conservation of angular momentum. We aren't sure exactly how, or how much of, the original star's rotation is passed to the black hole, but we know that the black hole likely will form with angular momentum.

You can visualize this momentum as the rate of rotation of the black hole's event horizon, which is the boundary separating the remnant singularity from the outside universe, within which you'd need a velocity greater than the speed of light to escape the black hole's gravity.

Measuring how fast a black hole spins is important in astronomy for three main reasons. First, spin is one of only two properties that define a black hole (the other is its mass). Second, we think spin is partly responsible for driving energetic outflows — like jets — away from black holes. These outflows can dramatically influence black hole surroundings and even limit their host galaxies' growth. Finally, supermassive black holes at the centers of galaxies are likely the products of two processes: mergers of many smaller black holes over billions of years and accretion of nearby gas. Measuring the spins of these supermassive black holes can tell us about the relative importance of those two processes.

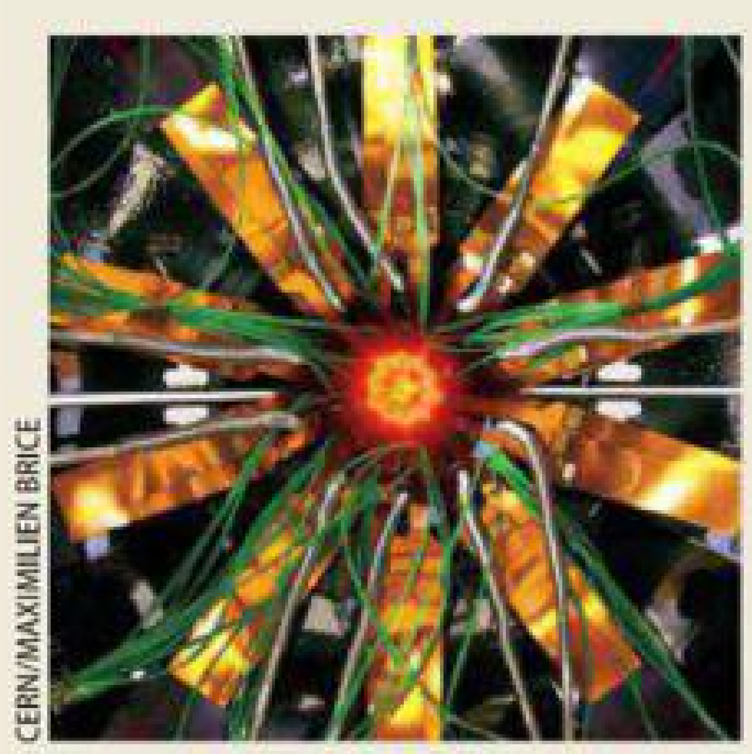


By looking for light distortions in X-rays streaming off material near black holes, researchers can gain information about their spins. The accretion disk also spins, and not necessarily in the same direction as the black hole.

We can't see a black hole itself (it's "black" because no light can escape from it), and we do not yet have the imaging capability to take a picture of the material swirling immediately around one before falling in. But we can measure a black hole's spin using two indirect techniques, both of which rely on examining X-ray light emitted from gas that is about to fall into the hole. We focus on X-rays because a black hole's rotation affects only the area nearest to the event horizon, where the gas gives off a lot of high-energy light. Specifically, we analyze the detected amount of a given energy, or radiation wavelength — called a spectrum.

In the first technique, we measure the temperature at the inner portion of the accretion disk that forms as gas swirls toward the event horizon, similar to water swirling down a drain. In the second method, we characterize the precise shape of certain spectral lines emitted from the innermost parts of this accretion disk. Both methods require high-quality X-ray spectral data.

These techniques also require detailed theoretical models that



Scientists studied data of the material produced after two streams of lead nuclei collided at the center of A Large Ion Collider Experiment (ALICE) at the Large Hadron Collider.

Q: DOES TEMPERATURE HAVE AN UPPER LIMIT LIKE THE LOWER LIMIT OF ABSOLUTE ZERO? WHAT'S THE HIGHEST MEASURED VALUE?

Jane Haldiman, *Chicago*

A: The universe's "absolute high" temperature correlates to the energy and heat that existed during the Big Bang. The physics rule that energy must be conserved doesn't allow any more energy than that which existed at the universe's beginning. The highest temperature that scientists have created — and thus measured — is 2 trillion kelvins. That was in the "quark-gluon plasma" created in an experiment at the Large Hadron Collider in Europe. Two streams of lead nuclei traveled toward each other at nearly light-speed. When they collided, they produced a hot plasma — the fourth state of matter made of ionized gas. — ***Liz Kruesi,*** *Associate Editor*

incorporate Albert Einstein's theory of relativity to extract all the possible information from the data and to get the most precise, accurate constraints on black hole spin. It's a painstaking process, but so far astronomers have successfully measured such spins in more than 20 supermassive black holes and more than 15 stellar-mass black holes in the past decade.

Laura Brenneman
Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts

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Q: HAVE ASTRONOMERS LEARNED MORE ABOUT THE "DARK FLOW"? IS IT REAL?

Bob Honicutt
Ware Shoals, South Carolina

A: When photons scatter off electrons moving toward us, the photons gain energy; when photons scatter off electrons moving away from us, they lose energy. This effect is called the kinematic Sunyaev-Zeldovich (kSZ) effect.

In 2008, Alexander Kashlinsky and his collaborators claimed the detection of a "dark flow" after analyzing this kSZ effect in the cosmic microwave background (CMB), the residual radiation throughout the universe due to the Big Bang. Using data from the Wilkinson Microwave Anisotropy Probe (WMAP), they measured the temperature of the CMB and the positions of clusters of galaxies; the researchers inferred that large regions of the nearby universe were moving coherently. These large related velocities, dubbed a dark flow, posed a significant challenge to standard cosmology theory that the universe looks the same everywhere on large scales. Many cosmologists doubted these claims and identified concerns in the analysis.

Last year, the team associated with the Planck CMB probe analyzed its data and looked for this bulk flow. With higher spatial resolution and sensitivity than WMAP, the Planck instruments are much more responsive to these dark flows. Using the same cluster sample and more sensitive CMB data, they did not detect the flow and found that if it does exist but is hidden in the data, its velocity is less than 158 miles/second (254 km/s), several times below what Kashlinsky's team claimed.

Although the dark flow probably isn't real, cosmologists have used the kSZ effect to detect galaxy motions on large scales. While a Princeton University undergraduate student, Nick Hand led a group of scientists who used data from the Sloan Digital Sky Survey and the Atacama Cosmology Telescope to study galaxy cluster motions. The amplitude of the signal that they detected is much smaller than that claimed by Kashlinsky and colleagues and is consistent with the standard cosmological model.

While the dark flow has "disappeared," the kSZ effect will likely remain an important tool for tracing the evolution of the universe and inferring the nature of dark energy — the mysterious "something" that's speeding up cosmic expansion.

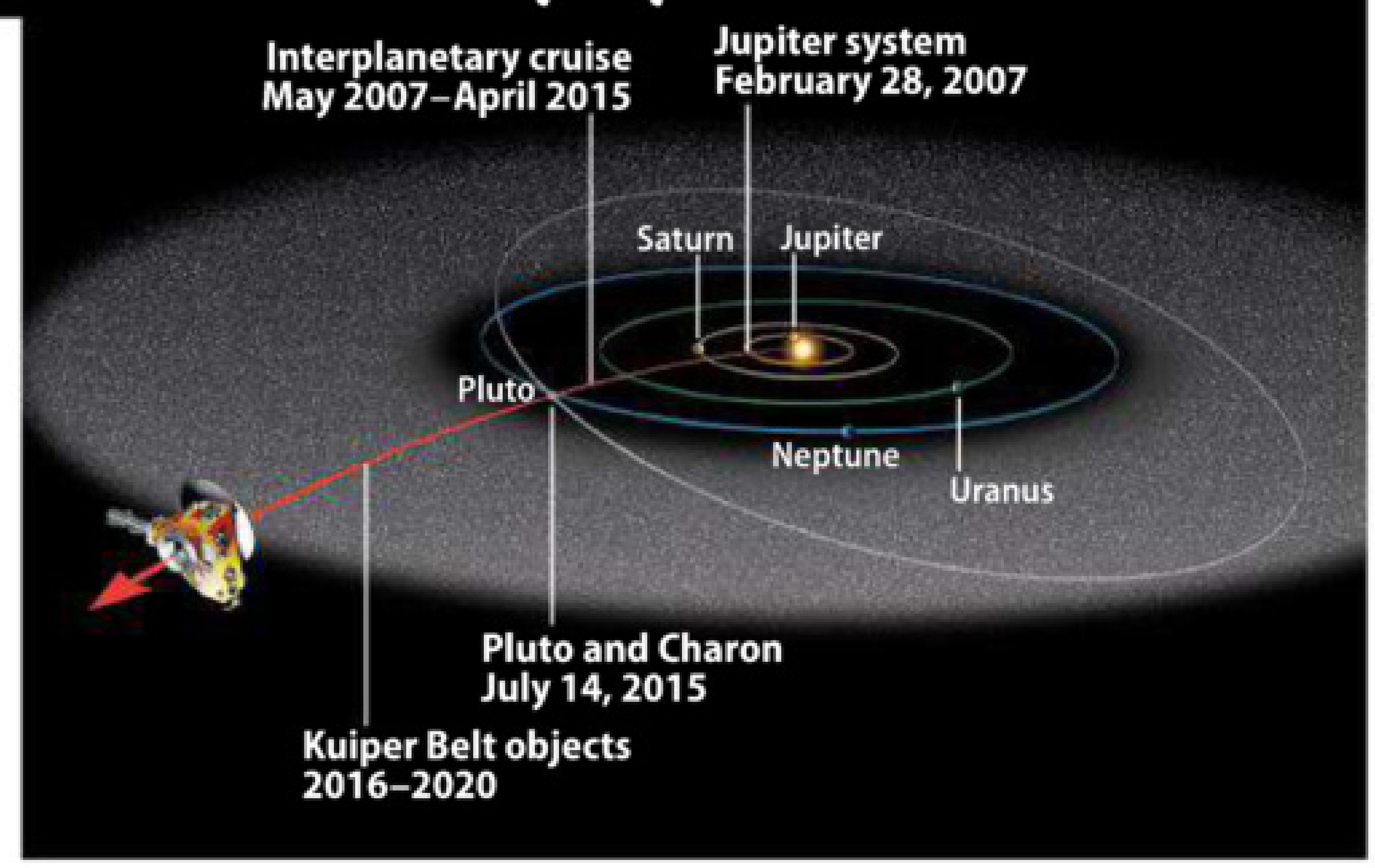
David Spergel
Princeton University, New Jersey

Q: HOW DOES THE NEW HORIZONS MISSION TEAM INTEND TO TARGET ADDITIONAL OBJECTS IN THE KUIPER BELT, AND HOW WILL THE CRAFT APPROACH THEM AFTER THE PLUTO SYSTEM ENCOUNTER?

Michael Schimpf
Pacific Grove, California

A: While there is an incredible dispersion of orbits for objects in the Kuiper Belt, only an extremely small fraction of those bodies are potential targets for the New Horizons spacecraft.

Far-out flyby



The New Horizons spacecraft will pass Pluto and Charon in July 2015. A few years later, the probe will investigate another Kuiper Belt object, still to be determined. *ASTRONOMY:* ROEN KELLY

That's because the fuel available for a post-Pluto trajectory change maneuver (which we call "TCM") will allow the craft to fly by Kuiper Belt objects (KBOs) whose orbits bring them within only approximately 0.5° of the current New Horizons spacecraft trajectory.

And it's not enough for the KBO trajectory to simply cross through this "acceptance cone." That orbit must put the object at the right place when the New Horizons craft reaches that particular distance from the Sun.

Nevertheless, using what's known about the population distribution in the Kuiper Belt, the New Horizons team calculates that there is a high probability — between 90 and 95 percent — that a KBO larger than about 30 miles (50 kilometers) in diameter should be available for a flyby. The encounter most likely would take place roughly three years after the Pluto encounter, which occurs in July 2015, when the spacecraft is approximately 42 astronomical units from the Sun. (One astronomical unit is the average Earth-Sun distance.)

But first we have to find at least one suitable KBO target using either large ground-based telescopes or the Hubble Space Telescope. Our team has been working on this problem intensively during the past couple of years, and we've discovered more than three dozen new KBOs but none located within the New Horizons acceptance cone. We're continuing to search hard and still expect to find a targetable KBO during 2014. Stay tuned for that announcement!

After we discover such a KBO, we'll execute a TCM, probably in late 2015, to put the spacecraft's trajectory on a beeline toward that object. Approximately 40 to 50 days before the KBO encounter, the Long Range Reconnaissance Imager on New Horizons will start detecting the KBO, allowing us to refine the trajectory and maneuver the spacecraft to within approximately 16,000 miles (25,000km) of the KBO at the time of closest approach.

Hal Weaver
Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

March 2014: Venus rules before dawn

Venus shines brilliantly in the southeast before dawn this month, much as it did the evening of April 10, 2007, when the Pleiades star cluster lay just above it on the right side of this image. TUNÇ TEZEL

With Mars just one month away from opposition and peak visibility, March provides exquisite views of this nearby world from late evening until dawn. But the true star of these increasingly balmy evenings is Jupiter, which dazzles from dusk until the approach of dawn. The early morning March sky teems with planet activity, with Saturn looking wonderful as always and Mercury and Venus reaching their pinnacles just eight days apart.

Let's start our tour of the sky in the west shortly after darkness falls. **Uranus** lies 30° east of the Sun as March begins, so it hangs low in the evening sky. From mid-northern latitudes on the 1st, the planet stands about 10° above the horizon once twilight fades away.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

If you have a clear western horizon, grab your binoculars and try to spot the magnitude 5.9 planet. Use Epsilon (ε) and Delta (δ) Piscium as guides. These two 4th-magnitude stars lie 3.5° apart; Uranus stands 4.5° south-southwest of (below) Delta. The planet disappears into the twilight glow by mid-March.

You don't need to wait for total darkness to view the other early evening planet. **Jupiter** appears brilliant among the background stars of Gemini and lies nearly overhead during twilight. Because the giant planet is well north of the celestial equator, it doesn't set until nearly 4 A.M. Jupiter shines at magnitude –2.3 at midmonth, 25 times brighter than the Twins' brightest star, Pollux.

When viewed through a telescope, Jupiter is one of the finest sights in the heavens. Although its disk has slimmed more than 10 percent since its early January peak, it remains large (41" across in mid-March) and shows superb detail. The sharpest images should come in early evening when the planet lies highest in the sky.

Look for an alternating series of bright zones and darker belts running parallel to Jupiter's equator. You'll almost always see two belts, but several more pop into view during moments of good seeing. The Great Red Spot shows up approximately half the time — whenever the planet's rotation carries it onto the Earth-facing hemisphere.

Jupiter's four bright moons orbit their home world quickly enough that their positions change noticeably from night to night and often hour to hour. You typically will find at least one moon on each side of the planet, but rarely all four line up on one side. March 8 provides one such opportunity. Observers in eastern North America can catch them in the correct order, too, with Io closest to Jupiter followed by Europa, Ganymede, and Callisto. Within an hour after sunset, Ganymede and Europa swap positions.

But the moons put on their best show when they cast their dark shadows onto the jovian cloud tops. The finest such transit in March occurs on the 23rd when the shadows of both Io and Ganymede appear on the planet's disk at the same time. An hour after the Sun sets across central North America (it is already dark in the east), Io's shadow lies halfway across Jupiter. Io and Ganymede themselves stand 11" apart just off the planet's western limb.

An hour later, as Io's shadow prepares to lift back

The inner planets reach their peaks

Mercury and Venus achieve greatest elongation within eight days of each other this month, providing nice views for early risers. *ASTRONOMY*: ROEN KELLY

RISINGMOON

A crescent Moon extravaganza

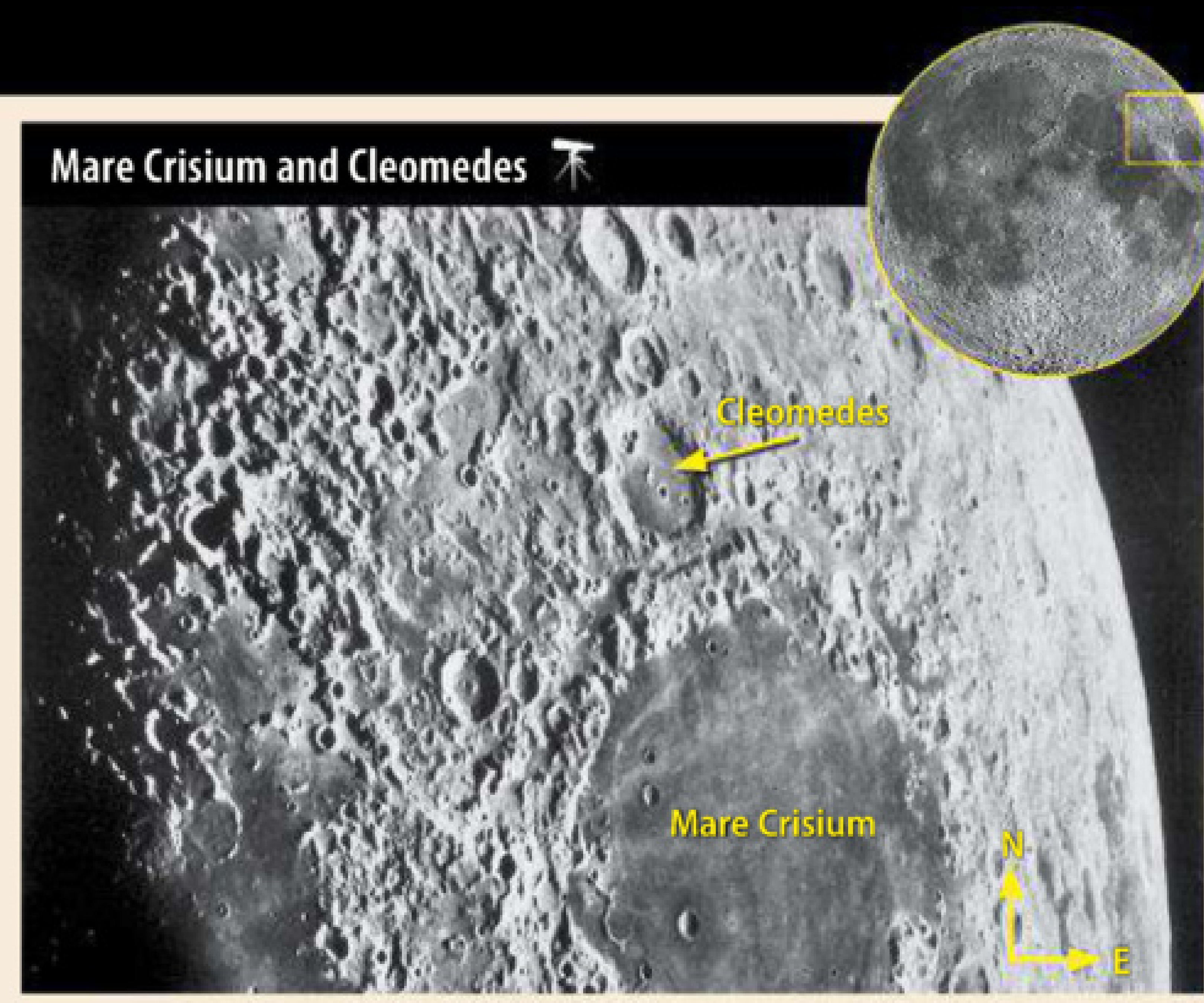
Moon-watchers love the early spring. The ecliptic rises almost vertically from the western horizon after sunset, which places the waxing crescent Moon higher in the evening sky than at other times of the year. The favorable geometry also aligns the crescent parallel to the horizon, giving it the look of the Cheshire Cat's smile.

Although a few experienced observers on the West Coast might spy the 18- or 19-hour-old lunar sliver on March's first night, most skywatchers will get their first peek on the 2nd. Earthshine — sunlight reflecting off our planet to the Moon and back again — should be prominent. Take a few minutes to pick out some Full Moon features on the dimly lit "dark side." Tycho's rays, brilliant Aristarchus, and several maria should be easy to see. In contrast, the jumble of bright and dark crater arcs on the lit crescent will be challenging to identify.

A significantly fatter crescent sits noticeably higher in the March 3 sky. Several recognizable landmarks dot the Moon's lit face this evening. In the north, half of Mare Crisium (the Sea of Crises) appears lit. Frozen lava covers the floor of this giant basin, and a ring of tall mountains surrounds it. In contrast to its name, Crisium's floor appears relatively tranquil. The shallow Sun angle highlights a wrinkle ridge near the sea's eastern shore. This feature formed when lava solidified billions of years ago and the ground subsided.

By March 4, all of Crisium lies in sunlight. Pump up your scope's magnification to find the smaller craters on the mare's floor; these will disappear under the higher Sun in a day or two. Next, look a bit north of Crisium for the crater Cleomedes. The lava-covered floor of this 78-mile-wide impact feature sports two fairly prominent craters measuring about 7 miles across. Cleomedes' inconspicuous central peak appears slightly off-center. Kick up the power again to look for Rima Cleomedes, a long, thin rille in the crater's northern half. Be patient for moments of good seeing, when the turbulent atmosphere above your head steadies.

Mare Crisium and Cleomedes



Mare Crisium is the first large basin to come into view after New Moon; you'll find the crater Cleomedes just north of it.

into space, Ganymede's larger shadow shows up on the opposite limb. Both shadows remain on the disk between 10:09 and 10:32 P.M. EDT. Ganymede's shadow leaves the disk about three hours later, at 1:26 A.M. EDT on the 24th. Pay attention to the relative separation between the moons and their shadows. Because the Sun illuminates the system from well west of our line of sight and Ganymede lies much farther from Jupiter than Io, the moons dwell near each other while their shadows appear far apart. It is a great illustration of the 3-D nature of the jovian system.

Whenever Jupiter is visible in the night sky, it shines brightly and looks impressive through a telescope. **Mars**, on the other hand, rarely appears either bright or impressive.

— Continued on page 42

METEORWATCH

Spring's subtle glow

While meteors are few and far between during March, the end of the month offers observers a great chance to see the zodiacal light. This ethereal glow — caused by sunlight reflecting off trillions of dust particles in the plane of the solar system (the ecliptic) — shows up best in early spring when the ecliptic makes a steep angle to the western horizon after sunset. Once the Moon leaves the evening sky around March 18, you'll have about two weeks to see the light.

The cone-shaped glow shines about as bright as the Milky Way, so you'll need a dark site to find it. Wait until twilight fades away completely; then scan back and forth above the western horizon with just your naked eyes. Under excellent conditions, people with good eyesight can trace the pyramid of light 50° into Taurus the Bull.

Zodiacal light

Dust in the inner solar system creates the ethereal zodiacal light, which shows up best in the evening sky during early spring. DALE CUPP

OBSERVING HIGHLIGHT Observers at mid-northern latitudes have a great chance to spot the zodiacal light after evening twilight ends from March 18 to 31.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth

STAR MAGNITUDES

Sirius
0.0
1.0
2.0
3.0
4.0
5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MARCH 2014

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

1 New Moon occurs at 3:00 A.M. EST

Asteroid Ceres is stationary, 3 P.M. EST

Mars is stationary, 4 P.M. EST

2 Saturn is stationary, 11 P.M. EST

3 The Moon passes 2° north of Uranus, 6 A.M. EST

5 Asteroid Vesta is stationary, 4 A.M. EST

6 Jupiter is stationary, 5 A.M. EST

8 First Quarter Moon occurs at 8:27 A.M. EST

10 The Moon passes 5° south of Jupiter, 7 A.M. EDT

11 The Moon is at apogee (251,881 miles from Earth), 3:47 P.M. EDT

14 Mercury is at greatest western elongation (28°), 3 A.M. EDT

16 Full Moon occurs at 1:08 P.M. EDT

18 The Moon passes 3° south of Mars, 11 P.M. EDT

20 Vernal equinox occurs at 12:57 P.M. EDT

20 The Moon passes 0.2° south of Saturn, 11 P.M. EDT

22 Mercury passes 1.2° south of Neptune, 8 A.M. EDT

SPECIAL OBSERVING DATE

22 Venus appears 47° west of the Sun at 4 P.M. EDT, which marks the peak of its current morning apparition.

23 Last Quarter Moon occurs at 9:46 P.M. EDT

24 Asteroid Pallas is stationary, 5 P.M. EDT

27 The Moon passes 4° north of Venus, 6 A.M. EDT

The Moon is at perigee (227,238 miles from Earth), 2:34 P.M. EDT

28 The Moon passes 5° north of Neptune, 10 A.M. EDT

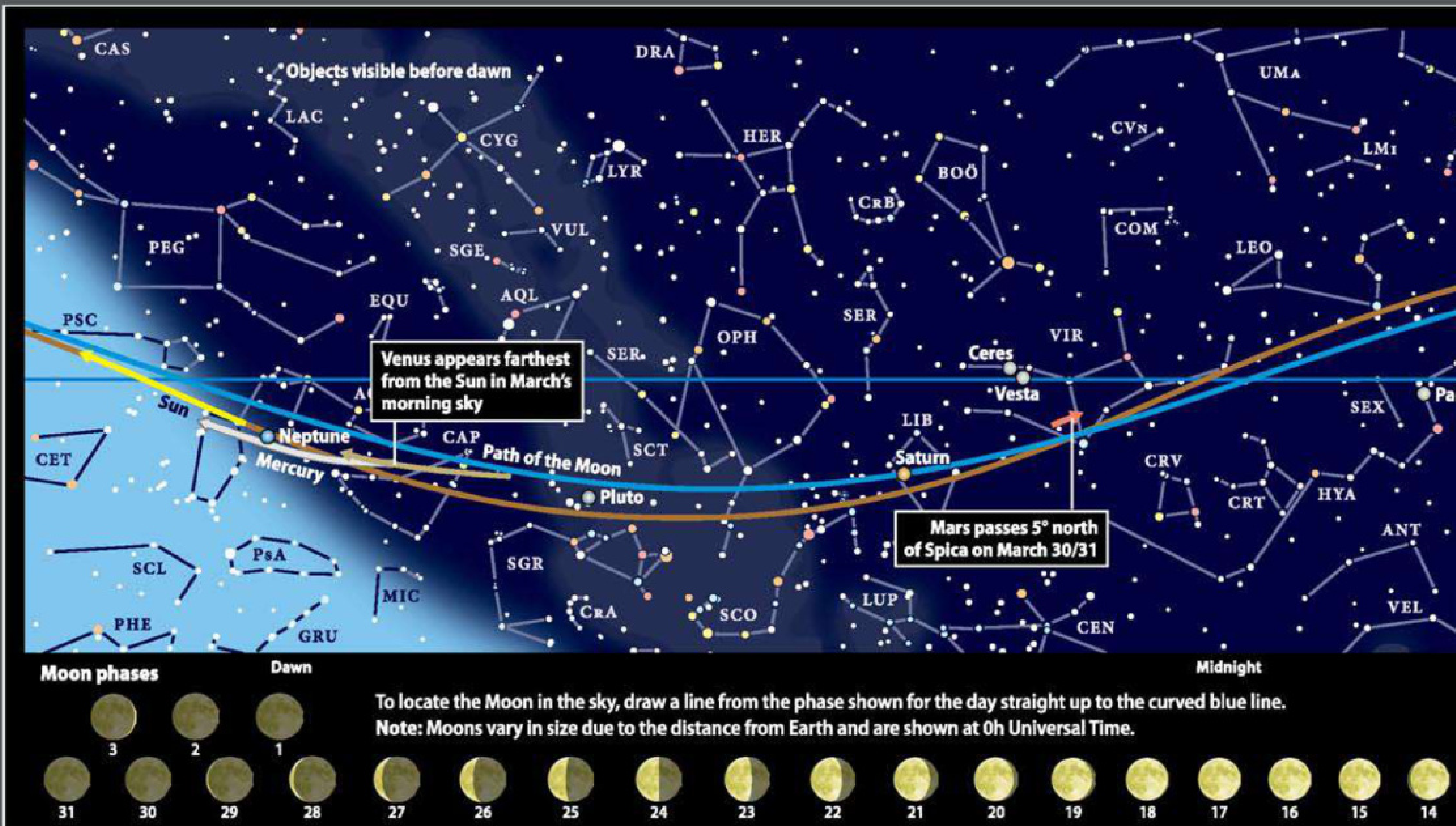
29 The Moon passes 6° north of Mercury, 1 A.M. EDT

30 New Moon occurs at 2:45 P.M. EDT

Mars passes 5° north of Spica, midnight EDT

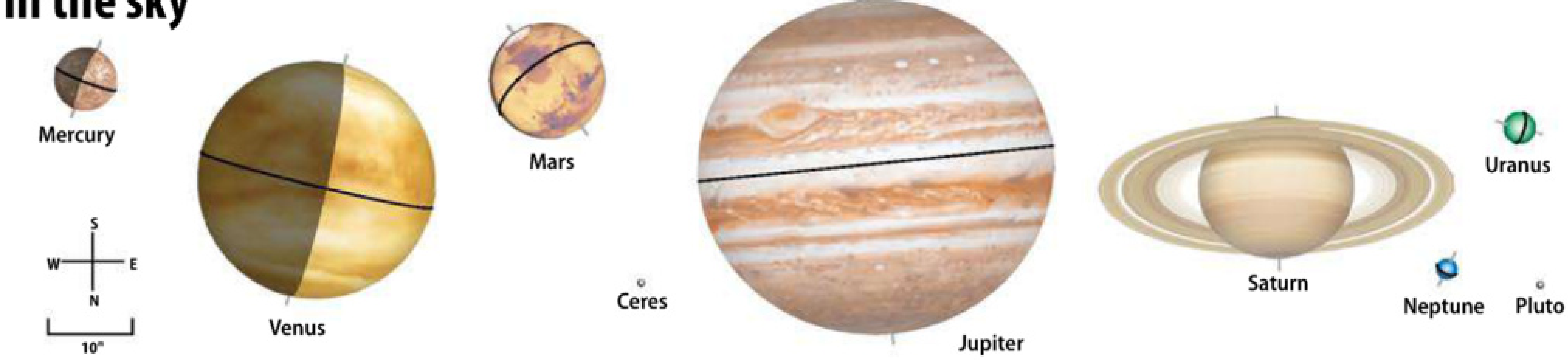
BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

The planets in March 2014



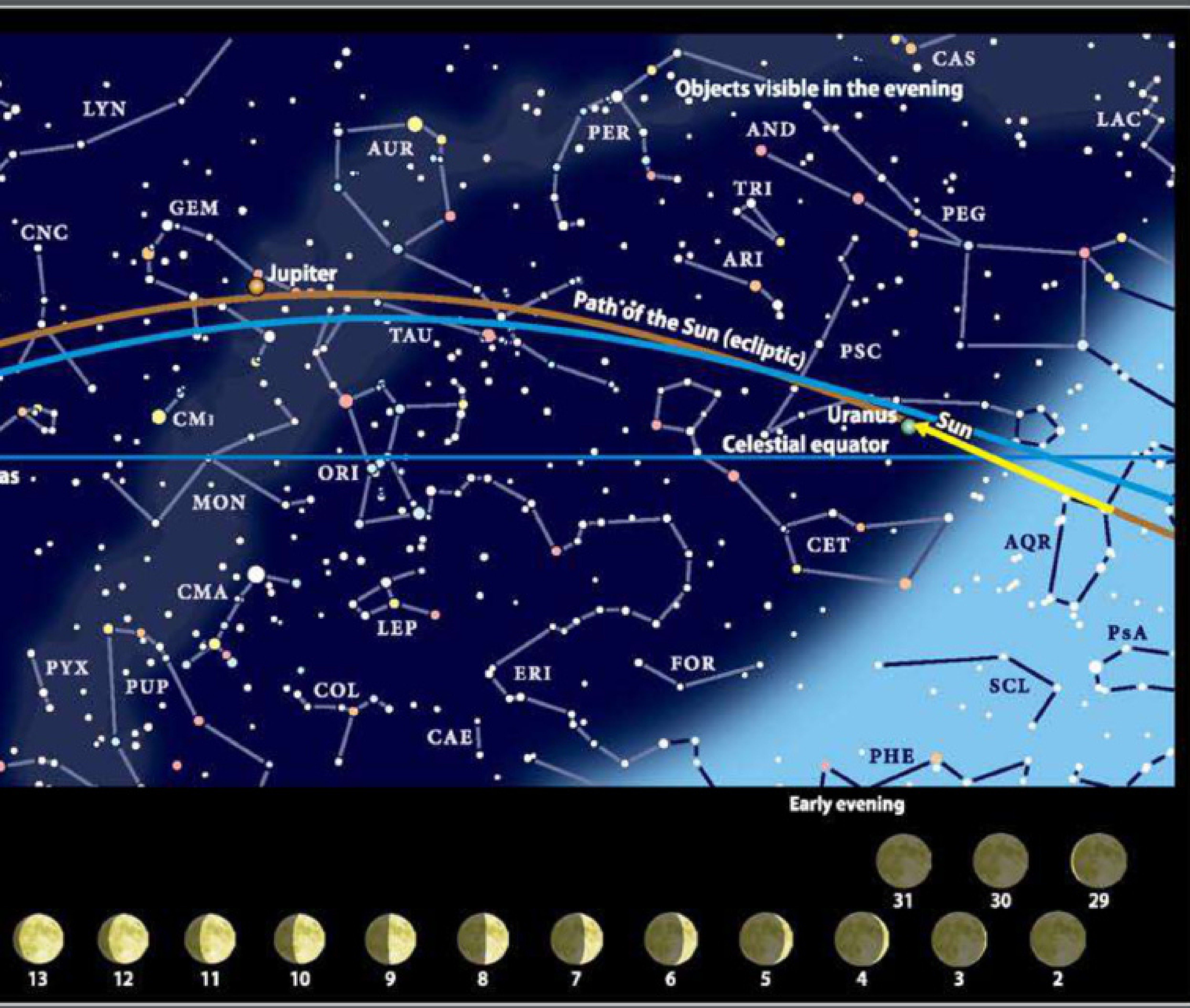
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



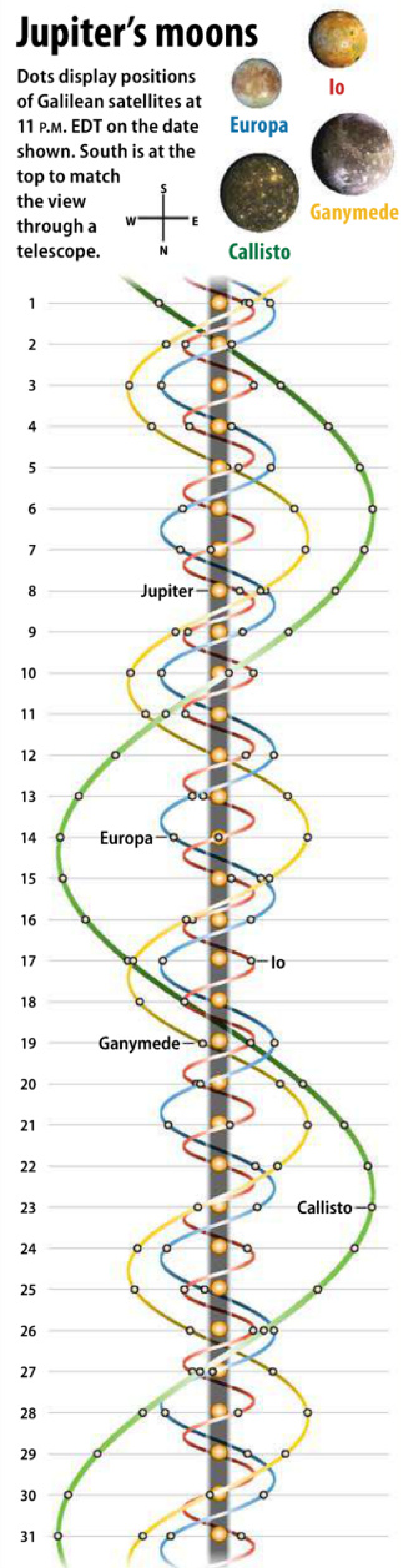
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	March 15	March 15	March 15	March 15	March 15	March 15	March 15	March 15	March 15
Magnitude	0.1	–4.6	–0.9	7.5	–2.3	0.4	5.9	8.0	14.2
Angular size	7.2"	27.0"	13.2"	0.8"	40.6"	17.8"	3.4"	2.2"	0.1"
Illumination	56%	45%	97%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.939	0.617	0.712	1.760	4.853	9.346	20.977	30.918	32.925
Distance (AU) from Sun	0.463	0.723	1.641	2.610	5.219	9.897	20.029	29.977	32.615
Right ascension (2000.0)	21h56.6m	20h38.1m	13h41.4m	14h14.2m	6h45.2m	15h24.9m	0h42.3m	22h30.5m	18h56.0m
Declination (2000.0)	–13°31'	–15°37'	–7°27'	1°28'	23°17'	–16°12'	3°51'	–10°06'	–20°07'

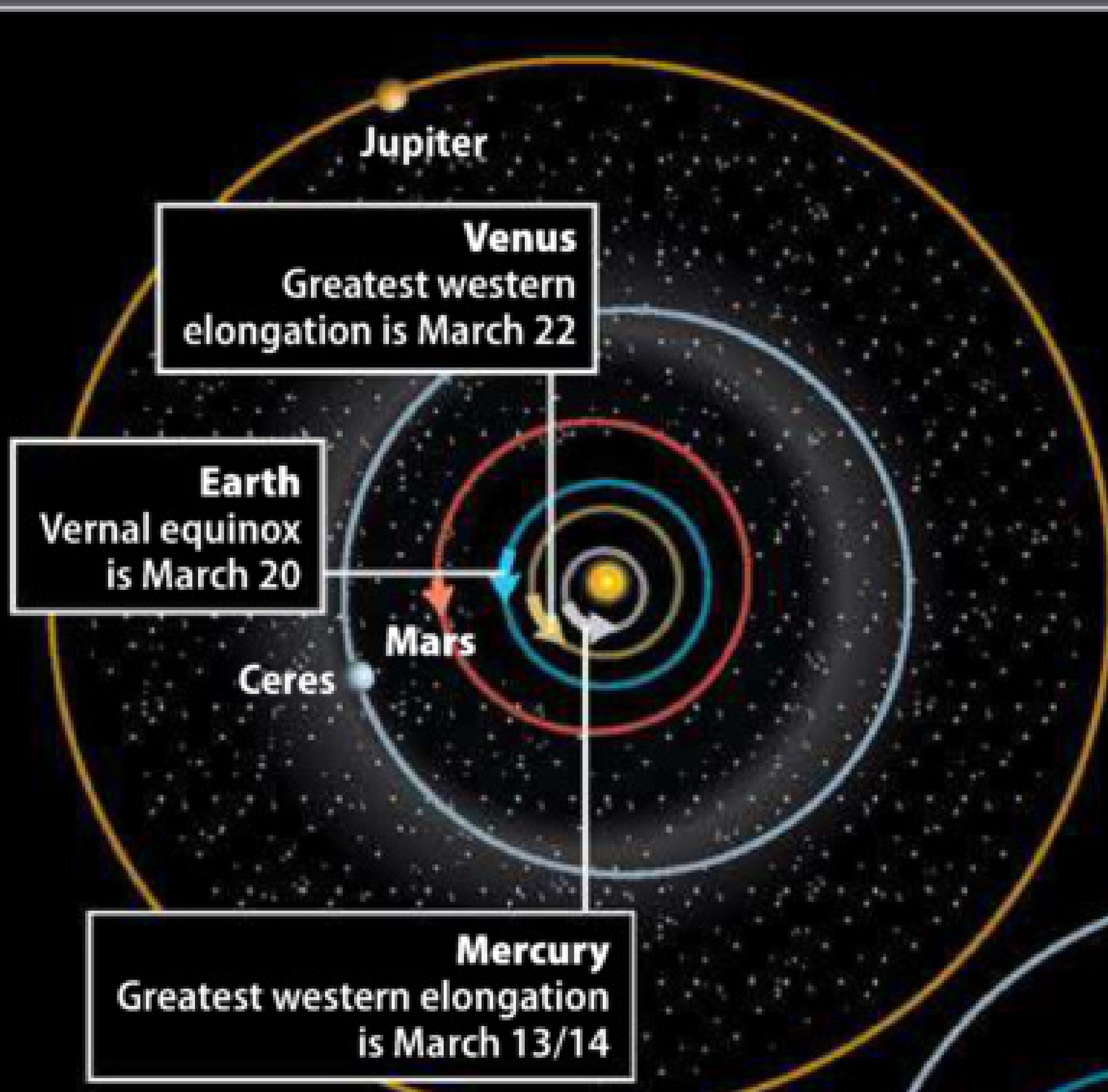
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

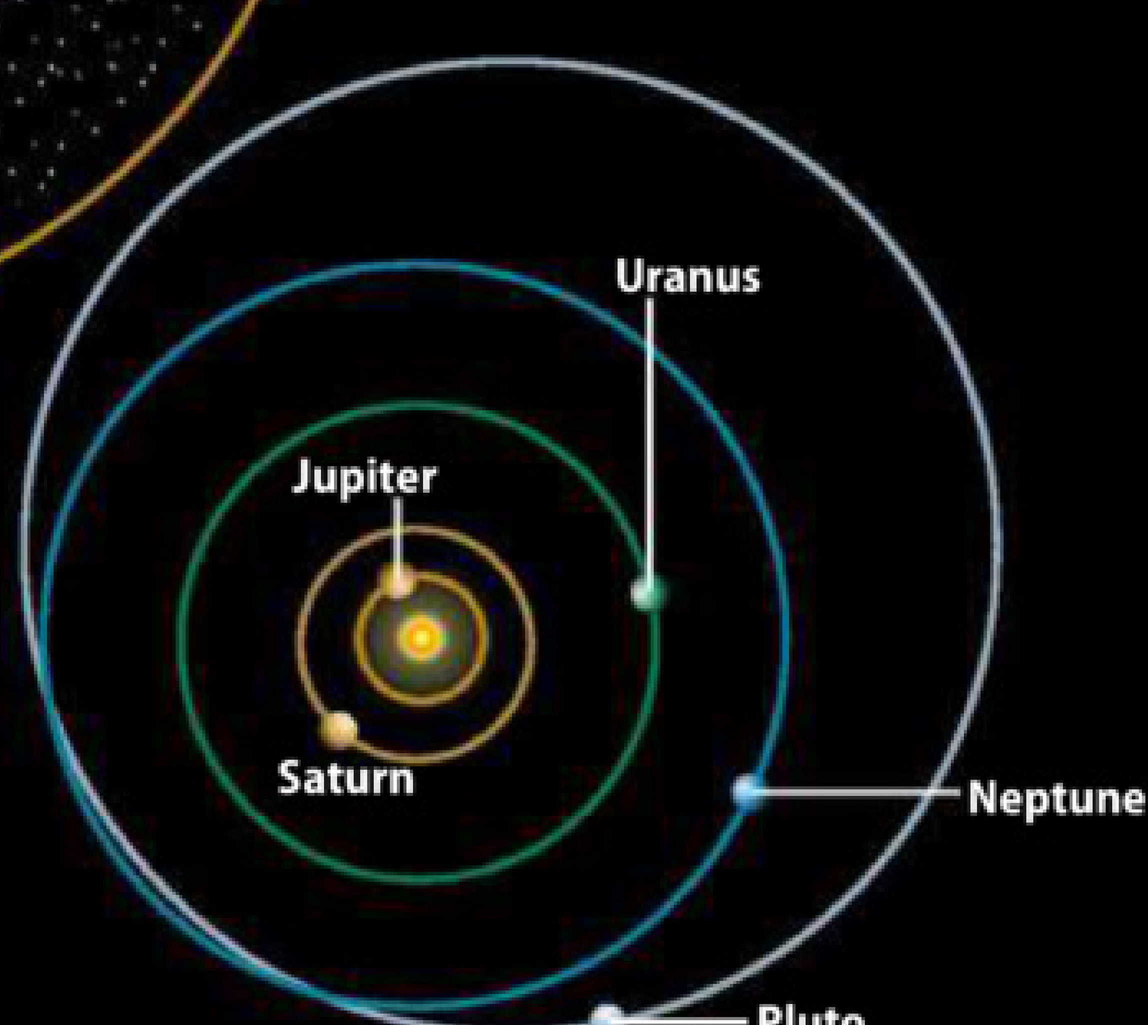


Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.







The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Jupiter (south)	Mars (southeast)	Mercury (east)
Uranus (west)	Jupiter (west)	Venus (southeast)
	Saturn (southeast)	Mars (southwest)
		Saturn (south)
		Neptune (east)

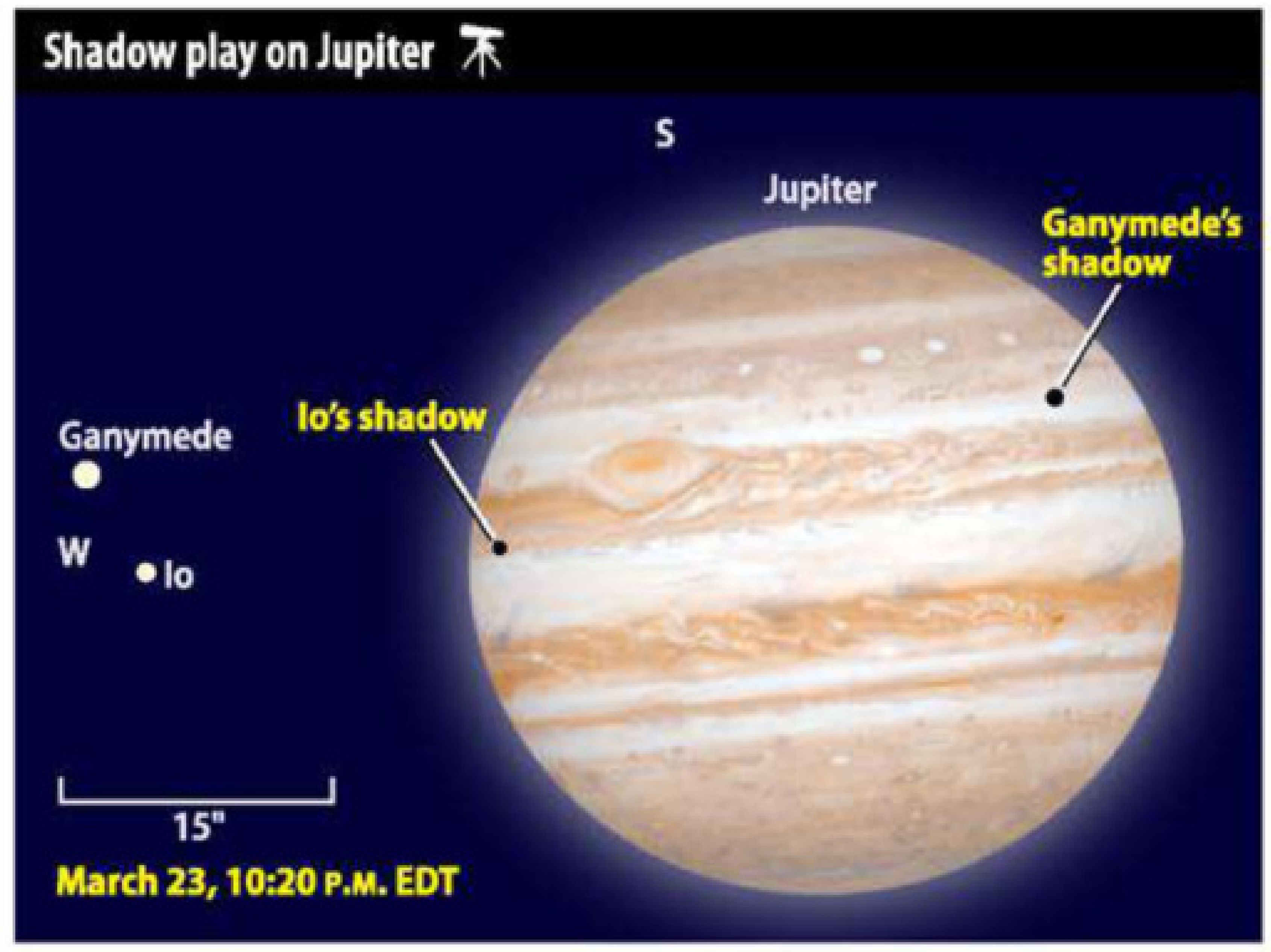
But for a few months every two years or so, the Red Planet morphs into a remarkable object that captures the attention of both casual naked-eye viewers and dedicated telescopic observers. That time has arrived.

Mars appears conspicuous throughout March, but it grows more prominent with each passing day. It rises around 9:30 P.M. local time early this month and during twilight by month's end. The Red Planet's brightness more than doubles in March, growing from magnitude –0.5 to –1.3, while the diameter of its disk swells by 25 percent, from 12" to 15". It will grow only another 0.5" by the time it peaks in April.

Mars becomes stationary against the stars of Virgo on March 1, some 6° northeast of the constellation's brightest star, Spica. The planet then starts trekking westward, reaching a point 5° due north of the star on the 31st. Notice the color difference between orangish Mars and bluish Spica. The contrast really stands out through binoculars.

The view through a telescope improves as the night goes on and the planet climbs higher. It reaches its peak around 3 A.M. local daylight time at midmonth when it lies about halfway between the southern horizon and the point directly overhead. The greater altitude means the planet's light travels through less of Earth's turbulent atmosphere, providing sharper images of the martian disk.

Mars' most conspicuous feature is its north polar cap. This bright white spot is well-positioned because the planet's north pole tips about 20° in our direction. The polar cap is shrinking as summer tightens its grip on that world's northern hemisphere, but it will remain prominent for several months.



Io and Ganymede simultaneously cast their shadows on the jovian cloud tops the evening of March 23. *ASTRONOMY*: ROEN KELLY

COMETSEARCH

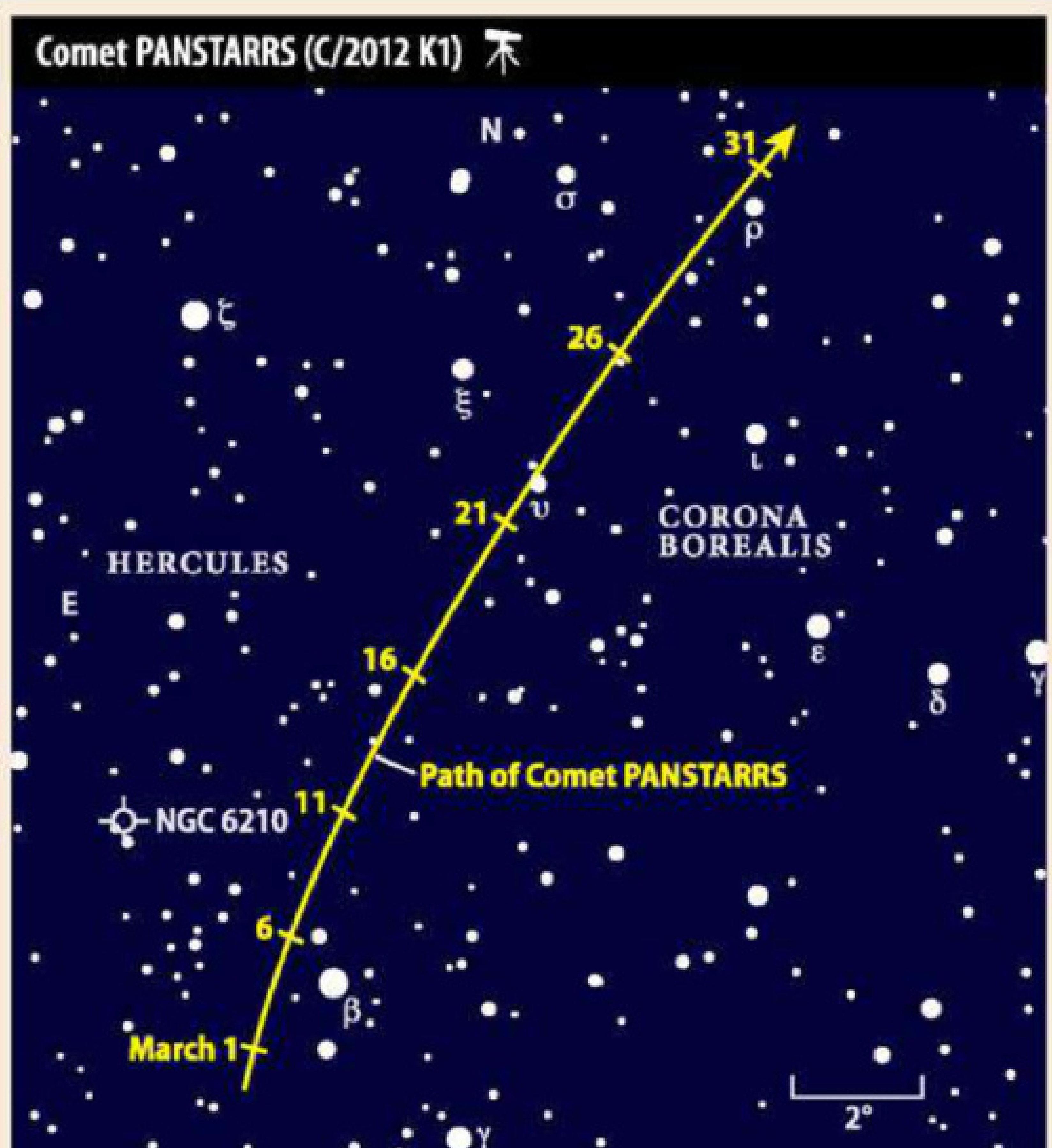
Say hello to another PANSTARRS comet

The sky is awash with comets named after the Panoramic Survey Telescope & Rapid Response System (Pan-STARRS) located on Haleakala in Hawaii. This 1.8-meter telescope is one of the world's most prolific comet-hunting machines. Barring some new discovery, 2014's brightest ball of ice and dust should be another Comet PANSTARRS: C/2012 K1.

Astronomers expect this cosmic interloper to become a decent binocular target by late summer. In March, however, it glows around 10th magnitude and appears as a puff of reflected sunlight. Under a dark sky, you'll need a 4-inch telescope to track down this visitor. You should use an 8-inch or larger instrument if you plan to view from a suburban backyard.

As March opens, look for PANSTARRS before dawn as it glides in front of the celestial strongman, Hercules. The comet is an easy 1.5° hop southeast of 3rd-magnitude Beta (β) Herculis. Three mornings later, PANSTARRS passes 0.9° due east of the star. While you're in the vicinity, slew another 3° east to catch the Turtle Nebula (NGC 6210). This well-defined greenish disk is a planetary nebula, the puffed-off outer layers of a dying star lit up by the ultrahot stellar remnant.

After mid-March, the comet crosses into Corona Borealis. It lies within 1° of 5th-magnitude Rho (ρ) Coronae Borealis on the month's final three days. By then, this region rises during the evening hours, though it is still highest before dawn.



The brightest comet this month glows around 10th magnitude as it moves slowly against the background of Hercules the Strongman. *ASTRONOMY*: ROEN KELLY

The Red Planet visits Virgo's brightest star in late March. The two offer a nice contrast in both brightness and color. *ASTRONOMY*: ROEN KELLY

The planet's most recognizable dark feature is Syrtis Major. This dusky region lies just north of Mars' equator and shows up best in March's fourth week when it lies near the center of the planet's disk around midnight EDT.

Saturn rises a little more than two hours after Mars. The ringed planet lies in Libra and reaches its maximum altitude shortly before morning twilight commences. Saturn shines at magnitude 0.4, more than two magnitudes brighter than any of Libra's stars.

Even small telescopes deliver impressive views of Saturn. This month, the planet's disk appears 18" across while the rings span 40" and tilt 23° to our line of sight. Saturn will grow bigger and shine brighter as its May 10 opposition approaches.

Modest telescopes can show you several of the ringed world's moons. Any instrument reveals 8th-magnitude Titan, but you'll likely need a 4-inch scope to spot the 10th-magnitude trio of Tethys, Dione, and Rhea. Titan's 16-day orbit brings it due south of Saturn on March 6 and 22 and due north March 15 and 31. The other three satellites all orbit Saturn in less than five days, so they typically change positions noticeably in a few hours.

Mercury and Venus both reach the peaks of their morning apparitions this month. Unfortunately, neither planet climbs high. The ecliptic — the apparent path of the Sun across the sky — makes a shallow angle to the eastern horizon before dawn in early spring. This means angular separation from the Sun translates more into distance along the horizon than altitude above it.

Venus fares far better than its inner neighbor, however. At greatest elongation on the 22nd, it lies 47° west of the Sun. It then rises two hours before our star and stands 15° high a half-hour before sunrise. But its brilliance is what sets it apart. Shining at magnitude –4.5, it appears more than two magnitudes brighter than Jupiter, the sky's second-brightest point of light. Five days after greatest elongation, on March 27, a crescent Moon passes 4° north of Venus.

Those who target the inner world through a telescope won't be disappointed. The period around greatest elongation is always a good one for seeing rapid changes. On March 1, the planet spans 33" and the Sun illuminates 36 percent of its disk. By the 31st, Venus' diameter has shrunk to 22" while its phase has waxed to 54 percent lit.

Mercury reaches greatest western elongation before dawn March 14. Although 28° separate it from the Sun, it appears only 5° high 30 minutes before sunrise. The planet shines at magnitude 0.1, bright enough to see through binoculars against the twilight glow.

LOCATING**ASTEROIDS**

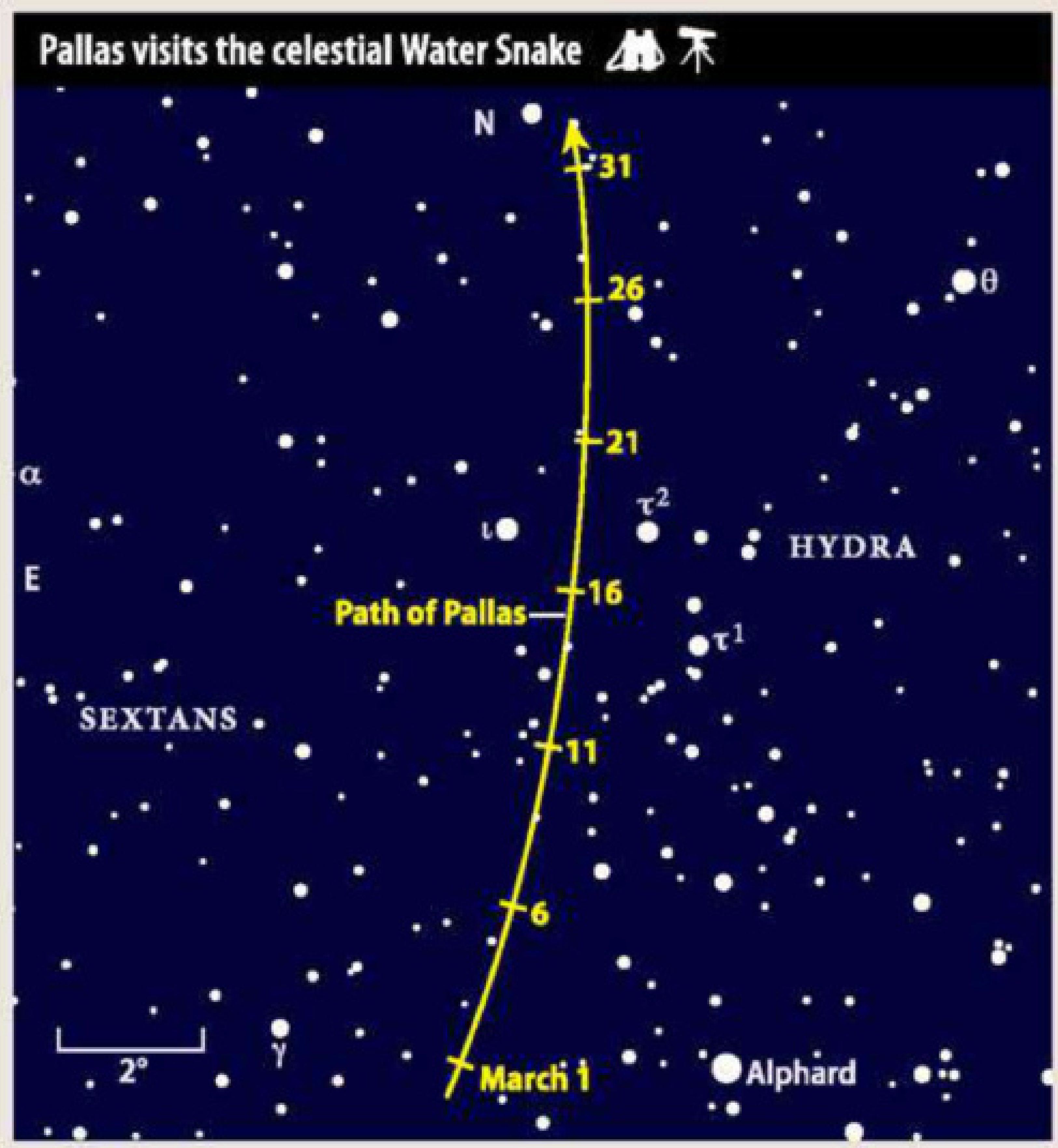
Pallas snakes its way across Hydra

The moderately elongated and highly inclined orbit of asteroid 2 Pallas means it doesn't grow bright very often. It shines at magnitude 7.0 in early March, the same as it did at opposition in late February. Pallas hasn't been this bright since 1991 and won't achieve a similar magnitude again until 2028.

The main-belt asteroid spends March trolling the celestial waters of Hydra the Water Snake. This region lies highest in the south during late evening. On March 1, Pallas passes 3° east of Hydra's brightest star, 2nd-magnitude Alphard. The asteroid heads nearly due north from there, a reflection of its high-inclination orbit.

Although Pallas appears relatively bright, it has to compete with the many background stars that lace the outer edges of the winter Milky Way. Use the chart below to hop to the space rock's position. Avoid the nights of March 11 to 15 when the bright Moon lies nearby.

German astronomer Heinrich Olbers discovered Pallas in March 1802, less than 15 months after Giuseppe Piazzi spotted the first asteroid, Ceres. With a diameter of 325 miles, Pallas also ranks second in size to Ceres among the asteroids.



Use 2nd-magnitude Alphard as a guide to Pallas, a 7th-magnitude asteroid that should be easy to identify from the background stars. *ASTRONOMY*: ROEN KELLY

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

EXPLORING THE BIGGEST ASTEROIDS

The Dawn spacecraft, once orbiting Vesta, is now headed toward Ceres. These two huge asteroids may represent the missing links between space pebbles and habitable planets. **by Sarah Scoles**

In the beginning,

the solar system was merely a solar nebula — a collapsed disk of gas and dust spinning around a central hub. In the cloud, particles randomly hit each other and stuck together. These amalgamations then collided with other ones, snowballing ever larger. As they grew, so did their gravity, and when they reached kilometer-size and became "planetesimals," they tugged their neighbors toward them. The planetesimals' attraction caused more smash-ups and produced even bigger bodies. Small pieces of the solar system combined into planetary embryos known as protoplanets. Some of these were lucky enough to grow into full-fledged worlds, the names of which are familiar to us today.

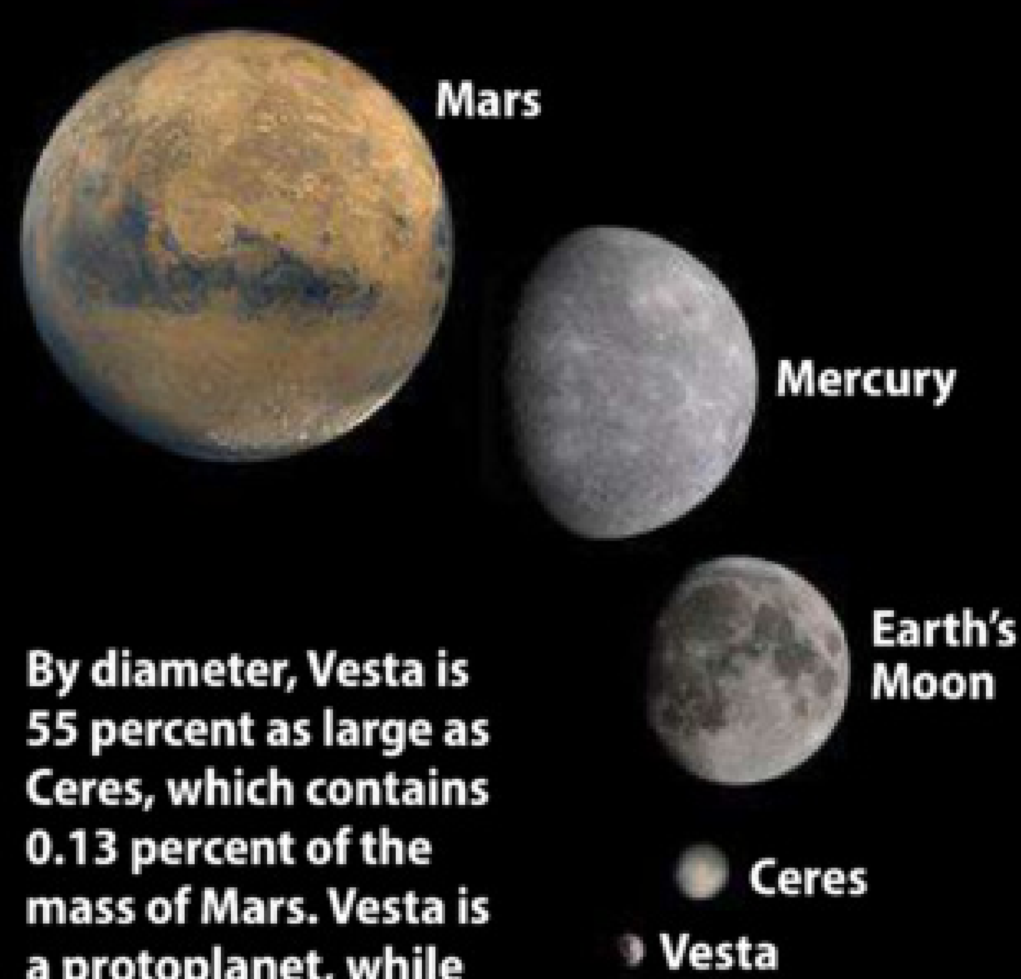
But most objects were unable to have the *proto* removed from their designations. As a young Jupiter boomed, it stole material from the smaller protoplanets, shepherded stray rocks such that collisions became less likely, and rudely arrested most of the others' development.

Sarah Scoles *is an associate editor of* Astronomy.

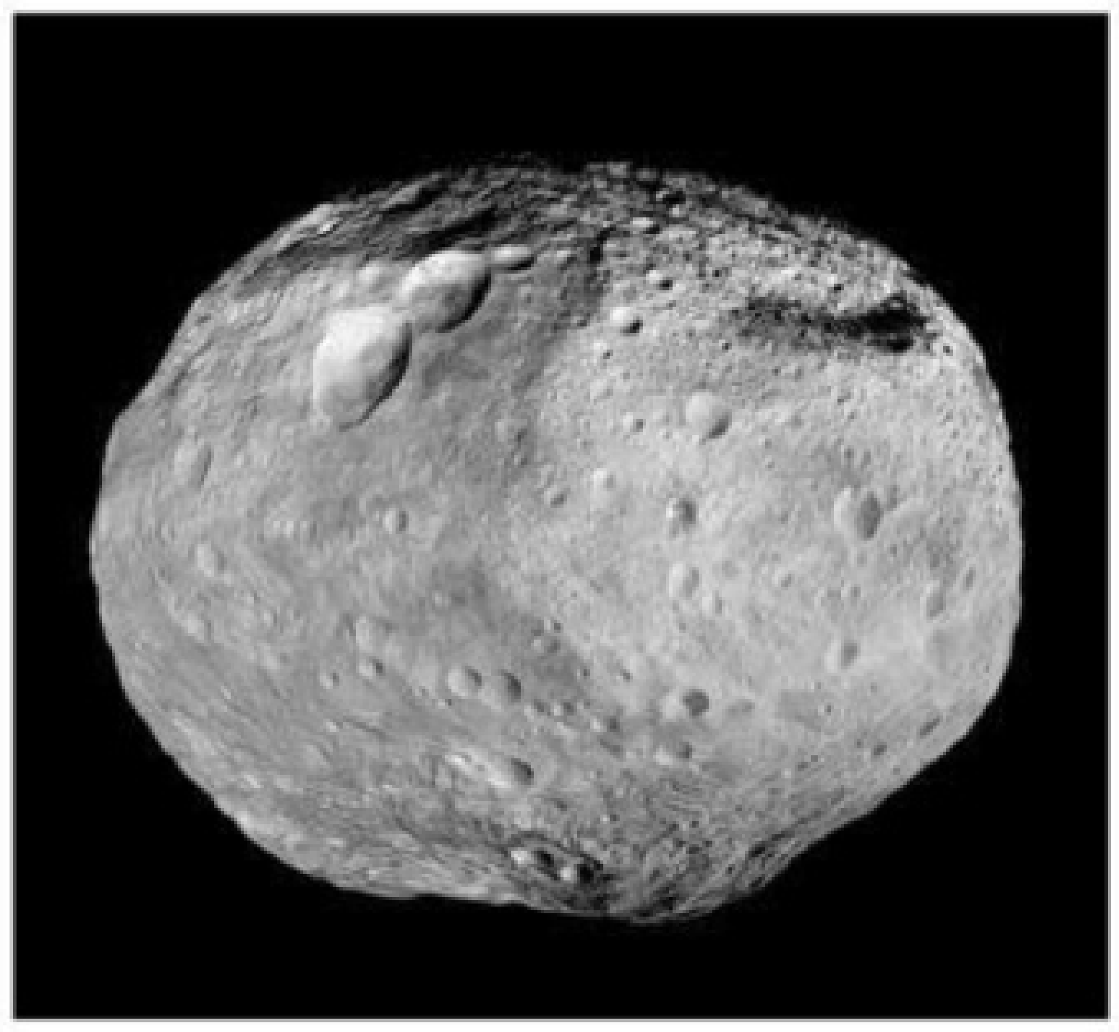
These immature bodies — which include leftovers ranging from dwarf planets to particles of dust — are huge in number. Extending more than a light-year from the Sun, the Oort Cloud, from which long-period comets come, has trillions of members, all flung into distant orbits because of the giant planets' gravitational disturbances. The Kuiper Belt, a collection of icy objects located at Neptune's orbit and beyond, has more than 1,000 known members. Some 440,000 known asteroids populate the asteroid belt, and the total may be in the millions. In short, the solar system is full of large objects that are not quite planets and not quite unvarnished chunks, which brings us to the two most massive asteroids, 1 Ceres and 4 Vesta, which number themselves among the planetary also-rans.

Just a few million years after the solar system began, Ceres and Vesta had already finished forming. Both are freeze-frames of the early solar system,

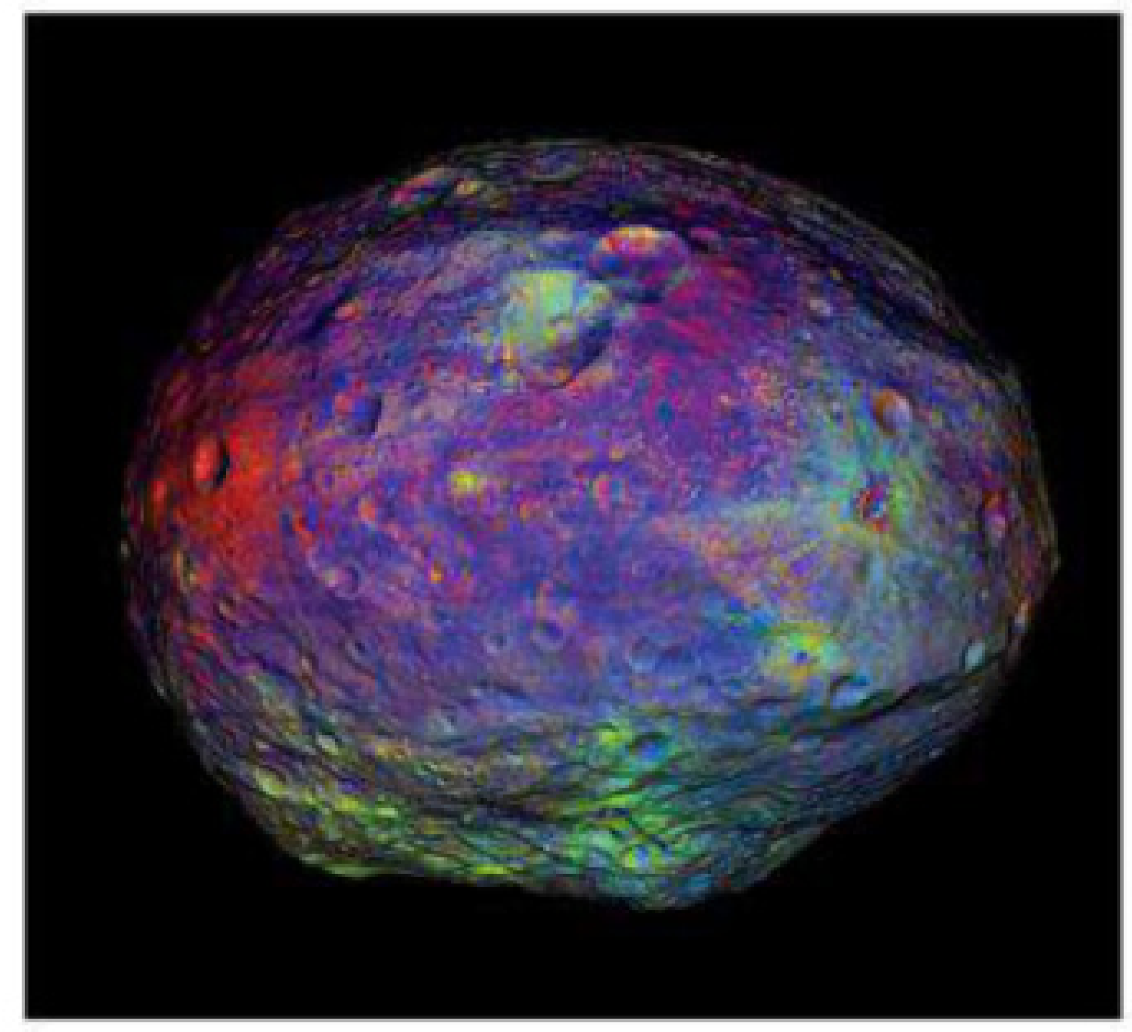
This false-color image from the Dawn spacecraft outlines the different materials — some ejected during an impact — that make up the asteroid Vesta's Antonia Crater. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA (CRATER); ORBITAL SCIENCES CORPORATION (SPACECRAFT)



By diameter, Vesta is 55 percent as large as Ceres, which contains 0.13 percent of the mass of Mars. Vesta is a protoplanet, while Ceres is a dwarf planet because its gravitation has made it a sphere, but it has not cleared its orbit of debris. NASA



Scientists put together the best views Dawn had taken of Vesta to create this mosaic image. The towering protrusion at the bottom is the edge of the Rheasilvia impact basin, while three craters together called the "snowman" are at the top left. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA



Scientists used Dawn's observations to create a 3-D model of Vesta, over which they draped a false-color image of the variation in its terrain and composition. Although scientists are still determining what each color means, they do know that green areas have a relatively high abundance of iron. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

allowing scientists to see a stage of its evolution that we otherwise would only be able to investigate using simulations. Vesta has a 14-mile-high (22 kilometers) mountain and craters deeper than any on Earth. Ceres, of which scientists only have fuzzy images, may have similarly extreme features. Together they make up a third of the asteroid belt's total mass.

NASA's Dawn mission is in the middle of a long journey to investigate both Ceres and Vesta. Dawn launched in 2007 and spent four years slicing through space toward dry rocky Vesta. The spacecraft orbited for nearly 14 months, taking high-resolution images that scientists are using to fill in the gaps between "swirling dust disk" and "current solar system." It set out for Ceres on September 5, 2012, and scientists will combine Dawn's observations of this world with those of Vesta to help explain how rocky planets form and acquire the water that now sustains the life on our rock.

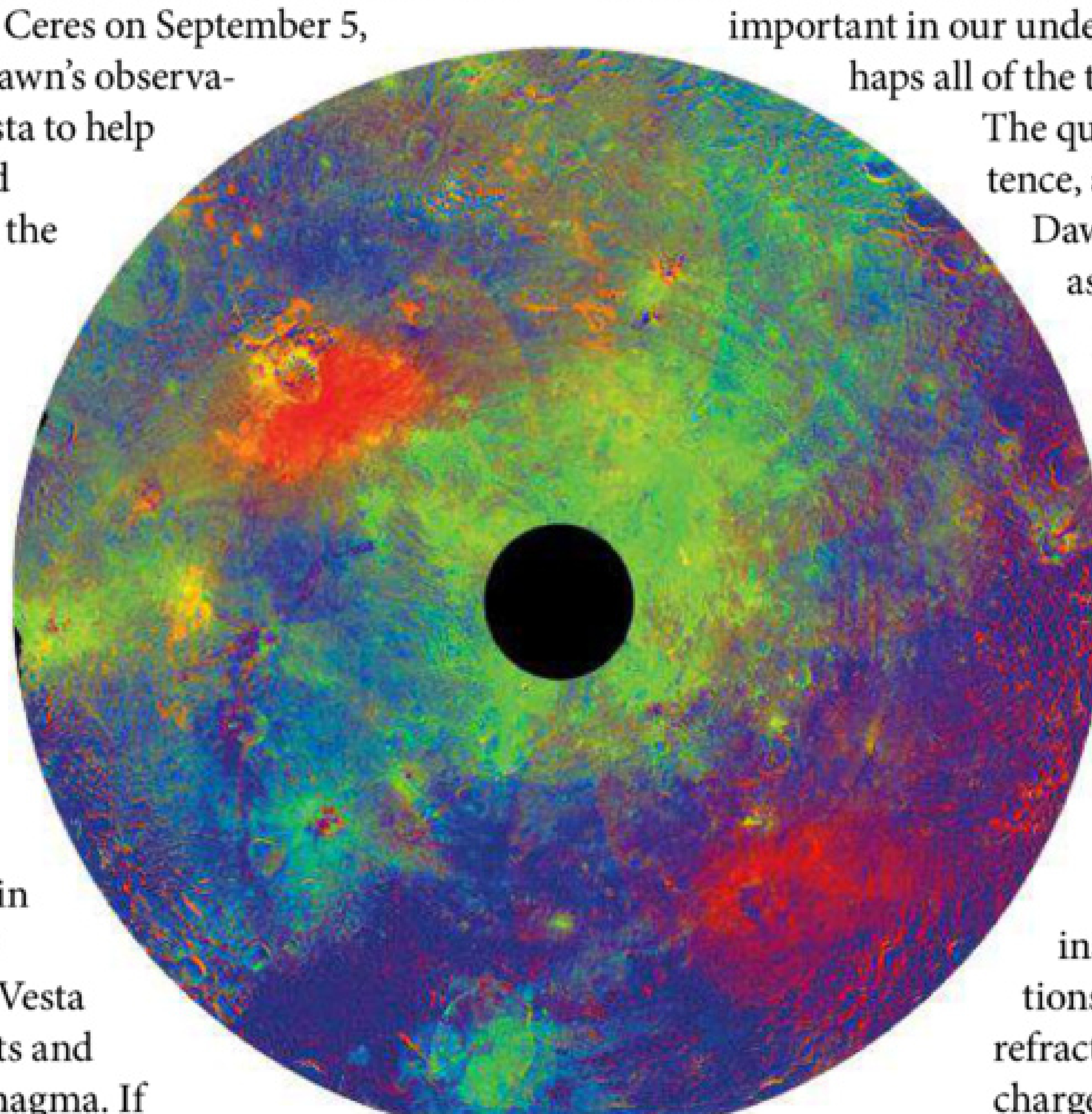
Mission motivation

Of the millions of asteroids, protoplanets, and dwarf planets out there, scientists picked Ceres and Vesta for several reasons. Their sizes mean they traveled further than other asteroids along the path to planethood. They are relatively nearby, at least compared to the Kuiper Belt objects. And perhaps most interestingly, they stand in illuminating contrast to each other.

Ceres is icy and primitive while Vesta is a dry wasteland blasted by impacts and smoothed by long-gone oceans of magma. If the two bodies both formed within the asteroid belt, how did they end up so different? The split between their personalities mirrors that between certain planets and satellites. "We know a lot about rocky terrestrial planets and about the icy moons of the outer solar system," says Dawn team member Ralf Jaumann of the German Aerospace Center's Institute of Planetary Research, "but we do not know anything about the transition between these two types of planetary bodies."

Dawn scientists' main motive is learning more about life-giving water in the solar system and how it was incorporated into planets like Earth. They do not know how much water is locked in asteroids, when the substance appeared there, or how it moves from one body, like an asteroid, to another, like a planet. "Ceres was expected to be water-rich and Vesta water-poor," says Christopher Russell, principal investigator for Dawn and a professor at the University of California, Los Angeles. "But it's not as poor as we had assumed. The origin of that water and how it was stored and preserved over the eons is important in our understanding of the asteroid belt and perhaps all of the terrestrial planets."

The questions of water's appearance, persistence, and migration are the heart of the Dawn mission, which fundamentally is asking how the solar system became a place in which we could survive.

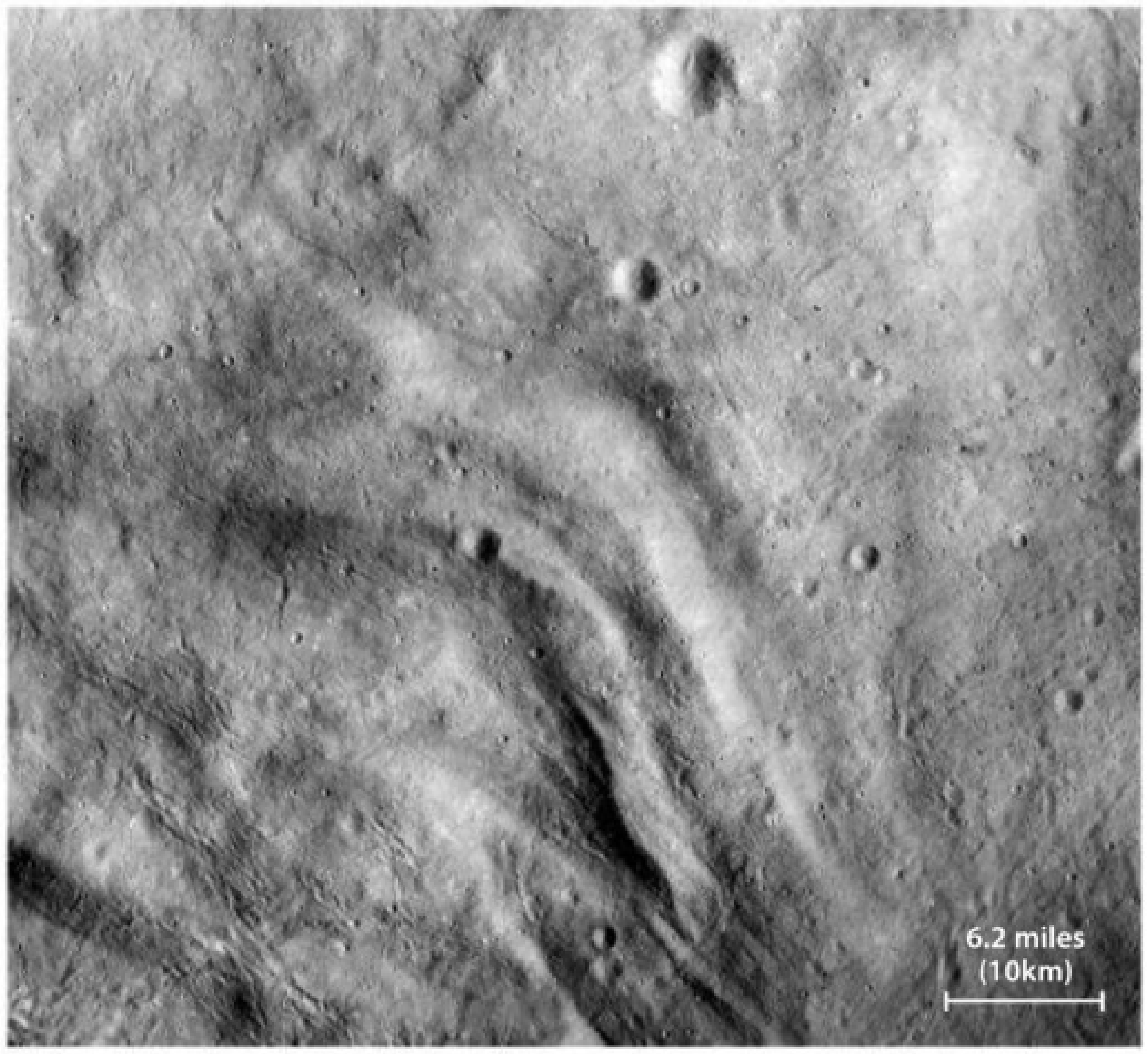


Across Dawn's southern pole stretches the imposing Rheasilvia formation, left from an impact that ejected 1 percent of Vesta's mass. This three-filter, false-color mosaic's green areas indicate iron-rich pyroxene or large particles, while scientists are still trying to determine what composes the blue and red areas. The black area in the middle contains no data because of the angle of the Sun. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

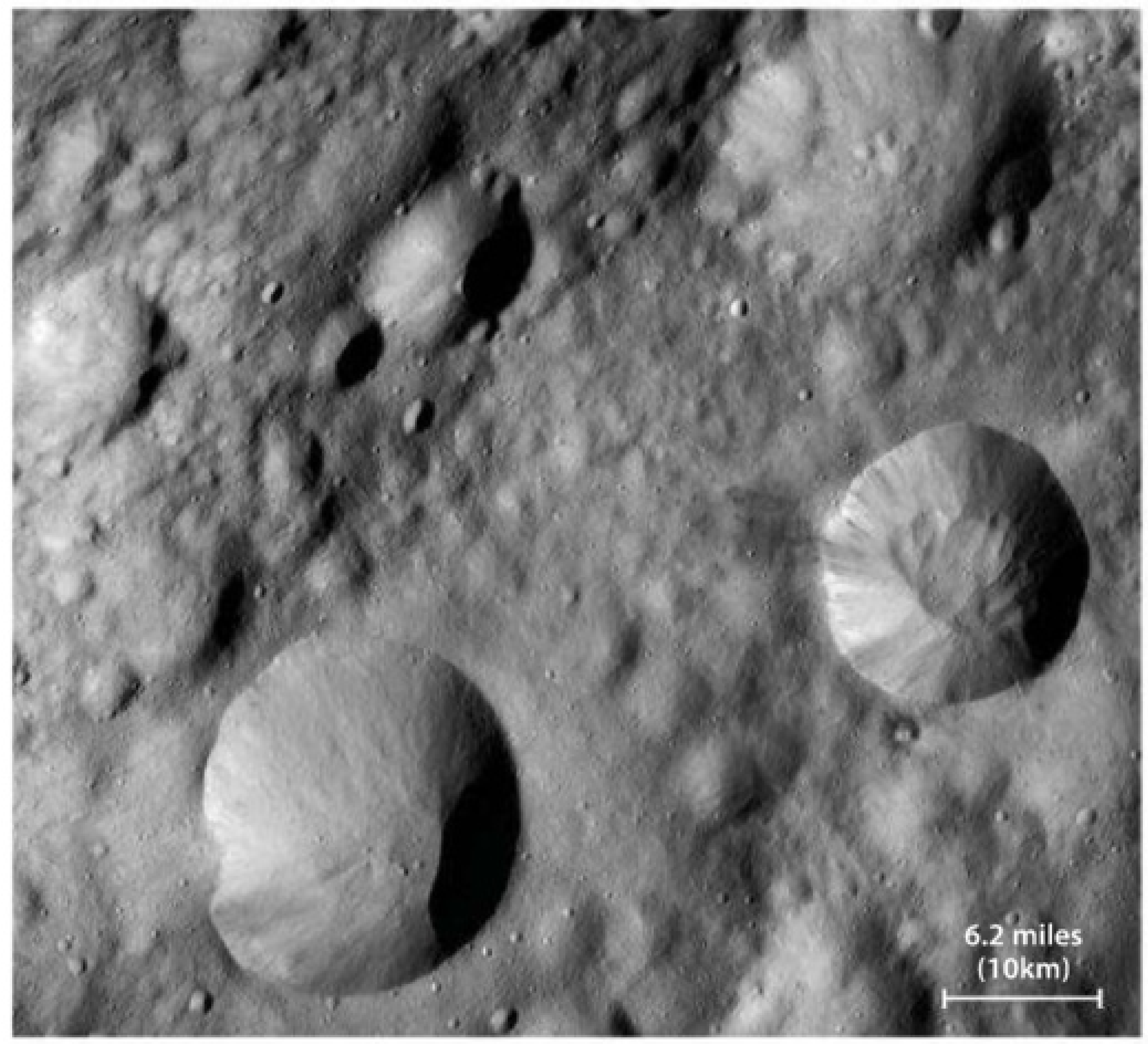
A view of Vesta

On Dawn's four-year journey from Earth to 326-mile-wide (525 kilometers) Vesta, it spiraled outward from our planet's orbit, catching a gravitational assist from Mars a year and a half into its journey. The boost propelled it into an even wider orbit, pushing it toward Vesta.

On board, Dawn carries three instruments to assist with its investigations. The Framing Camera (FC) — a refractive optics system connected to a charge-coupled device (CCD) — is useful for both scientific investigation and navigation: to see what is happening on Vesta, and eventually Ceres, and where the spacecraft is headed. Dawn also has an instrument called the Gamma Ray and Neutron Detector (GRaND), which sniffs out elements that form rock, like silicon, as well as radioactive elements and water. Finally, its Visual and



In Vesta's southern hemisphere, undulating ridges and depressions weave around Rheasilvia Crater. Each undulation's crest can extend for some tens of miles, and the ridges are separated by less than 6 miles (10 kilometers). NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA



Vesta's Publicia Crater (far right) has a sharp, fresh boundary. It is one of the "freshest" craters in this field of view, meaning its surface has not been covered with much material post-impact and it is likely the youngest crater in this image. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

Infrared Spectrometer (VIR) is designed to detect composition. VIR looks for the fingerprints of different surface atoms and compounds, making maps that show where each type of material is located.

Right away, the hydrogen-detecting instruments made an upending discovery. Despite scientists' belief that Vesta is dry, Dawn picked up signals from hydrated material — compounds bound to water molecules — on Vesta's surface. The spacecraft also saw evidence of underground ice. Vesta's apparent moisture may be the decoder ring for the puzzle of other solar system water, says Maria Cristina De Sanctis of the Institute for Space Astrophysics and Planetology in Rome: "We believe that the processes that formed this material on Vesta could have been responsible for the water delivery to the inner solar system." If Dawn scientists can figure out where rocky Vesta got its water, they may know how Earth, too, got its water. Like siblings, though they may have different hair colors, heights, and weights, Earth and Vesta were raised in the same environment.

The answer to the "how" of water is inherently connected to the "when." And scientists have learned about the "when" by connecting earthbound observations with those Dawn is making. The spacecraft traveled from Earth to Vesta, but parts of Vesta also have traveled to Earth. Astronomers long have thought that a common type of meteorite — called a howardite-eucrite-diogenite (HED) — originates on Vesta. The asteroid has a huge chunk bitten out of its southern pole, and researchers have speculated that if scooped up and stuffed back in that hole, the HED meteorites would fill it exactly, like pieces of a puzzle. Vesta's missing portion is 314 miles (505km) across and would be 1 percent of the asteroid's mass if it were still there. From the bottom of this crater to the top of its rim measures 14 miles (22km) — nearly 9 miles (14km) higher than Everest.

Space debris

The crater, named Rheasilvia, lies embedded in another, older crater called Veneneia. Both were created when Vesta collided with other substantial rocks at some point in its past. Because the asteroid was already large and dense during these encounters, it didn't merge with its impactors. Instead, the crashes created huge fractures that now show up as craters and troughs, like the ripples that appear when you throw a rock in a lake. Huge quantities of scooped-out rock — in Rheasilvia's case, 500,000 cubic miles (2.1 million cubic kilometers) of it — went flying into space.

Some of those pebbles must have ended up here on Earth, and scientists believed the HED meteorites, which have been raining down on Earth every so often for eons, were evidence of that. Like Vesta itself, the fragments appear to have formed just after the solar nebula began to condense, their primordial composition implies. Dawn's analysis of Vesta's composition shows that it matches the materials in the HED meteorites, connecting the asteroid's past impact and Earth's more current ones.

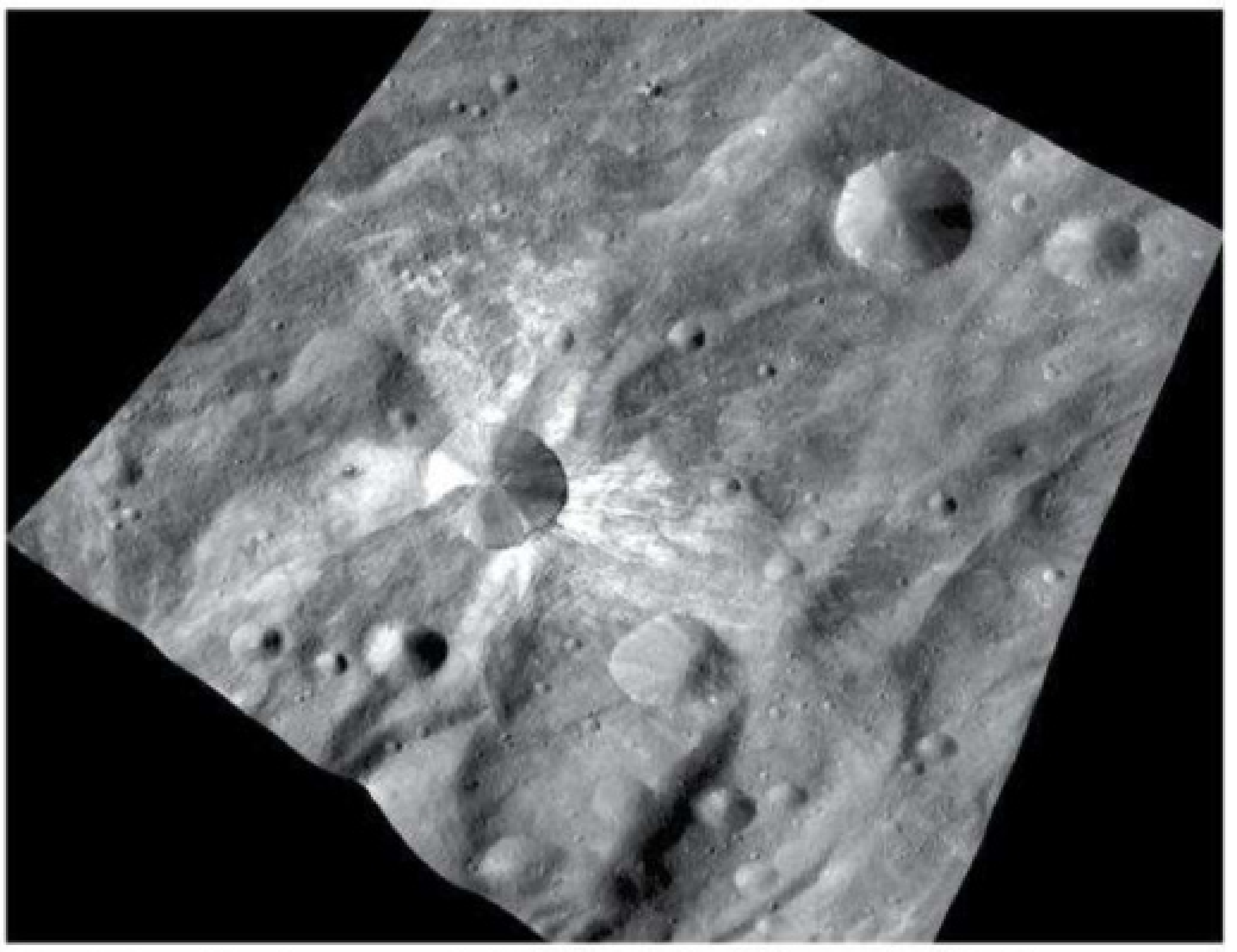
The composition of the HEDs — their namesake minerals — tells scientists that their original home must be layered, or differentiated, like planets are. Before Dawn, geologists postulated that Vesta's heavy iron sank into a core, leaving a mantle of olivine, a crust of diogenite, and eucrite as "the icing on the cake." Dawn's connection of the HED meteorites to Vesta confirmed that this geological model is correct.

Bombardment from space also changed Vesta's appearance. Dawn's images show a rocky world pocked by impact craters of all sizes, with rays of ejected and hardened material shooting out of the depressions. These craters range widely in age, suggesting other rocks have been hitting this one over the age of the solar system.

When a collision happens, materials from Vesta's interior combine with those from the impactor and spray across the surface. Some craters are especially deep because locked-in water ice heated up during impacts and then sublimated explosively out of the rock, turning directly to gas. After eons of such battering and bruising, the whole surface is covered in a layered sheet of debris between 330 feet (100 meters) and several miles thick. Vesta is the only asteroid that has survived this much outside attack and thus the only one that has a "fresh," exfoliated exterior.

Asteroid dermatology

But Dawn has shown that Vesta's fresh skin lacks a uniform pallor. Light and dark areas speckle and streak across the surface. Scientists



Vesta's Canuleia showcases the bright streaks of ejecta scientists have seen around many of its craters. Scientists believe this material comes from inside the asteroid and was excavated by impacts. NASA/JPL-CALTECH/UCLA/MPS/DLR/PSI/BROWN

Astronomers believe the troughs around Vesta's equator are shock-like remnants of ancient impacts. These features could not have formed if the asteroid did not have separate core, mantle, and crust layers. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

believe the lighter material, which appears in rays around craters, is native to Vesta. Dawn's VIR showed the dark material, however, to be full of carbon and found all over — in pockets dense or diffuse, small or large — instead of showing up preferentially at geological features. Because of this geographic variety, scientists have concluded that the dark material rained down on the planet.

Where Vesta's surface material is dark — a shade matching that of the carbonaceous chondrite meteorites that some scientists think first carried water to Earth — water is abundant. If carbonaceous chondrites hit the asteroid and left their dark marks and H_2O, the same process could have happened on Earth.

Curiously, the HEDs show no evidence of water or other volatile compounds, which means these molecules must have appeared on Vesta after Rheasilvia, a timeline that matches Earth's.

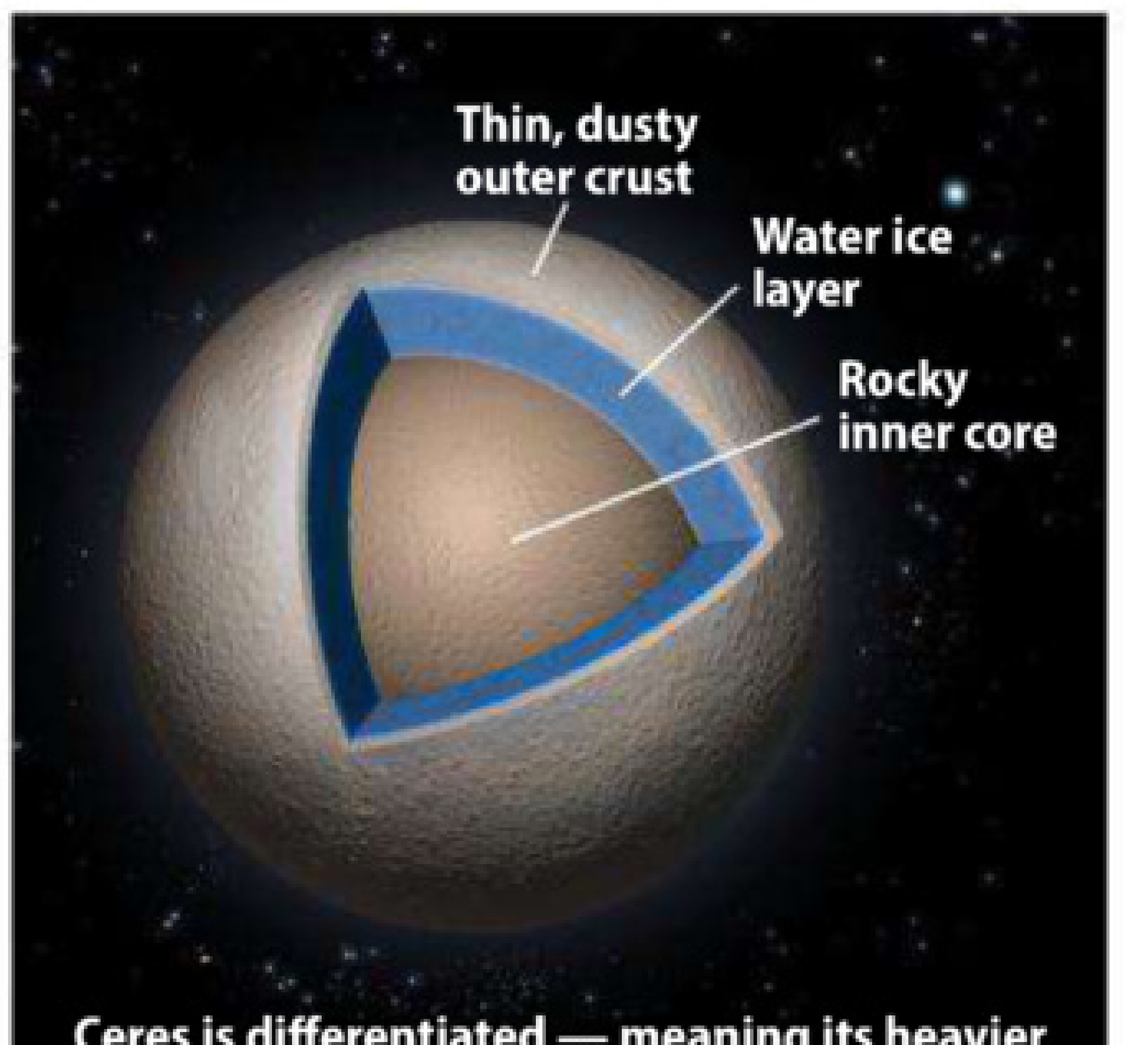
Based on the new results, Jaumann says, "Vesta's geology is more like the Moon and rocky planets than other asteroids." Russell takes it even further: "Vesta resembles a small planet more than a big asteroid. Even before Dawn arrived, Vesta had been called the littlest planet."

It is true that in Dawn's close-up portraits of Vesta, a distracted scientist could mistake the protoplanet's dips, rises, and gullies for those of Mars or the African Rift Valley. Such features suggest this strange body once had flowing water, which shaped the rock and then evaporated.

A space odyssey

With questions of Vesta's differentiation, water content, and geology at least partially answered, Dawn and the protoplanet parted ways, the spacecraft's ion propulsion system pushing it farther out into the solar system. Eventually, it will meet up with Ceres' orbit.

Once there, which it will not be until March 2015, Dawn will remain in orbit around the dwarf planet for 11 months. It will ease slowly closer to Ceres. First, it will orbit 3,700 miles (5,900km) above the surface, but in August 2015, it will drop to just 920 miles (1,480km). In November 2015, the spacecraft will skim just 230 miles (370km) up.



Ceres is differentiated — meaning its heavier components, like iron, have sunk to its middle and it is composed of increasingly light rocky layers — but its layers are different from Vesta's. While they both have a rocky inner core, Ceres may have a dusty outer crust, a water ice layer underneath, and a liquid water ocean beneath that. *ASTRONOMY*: ROEN KELLY

This proximity will produce unprecedented images of the 590-mile-wide (950km) dwarf planet/asteroid. The best picture scientists have of this world is fuzzy at best. Although Ceres is large for an asteroid and straightforward to detect, it is 260 million miles (419 million km) from the Sun, so snapping a detailed picture is no simple matter. "Ceres is really intriguing," says De Sanctis. "The available data are few. We know that it is large and dark."

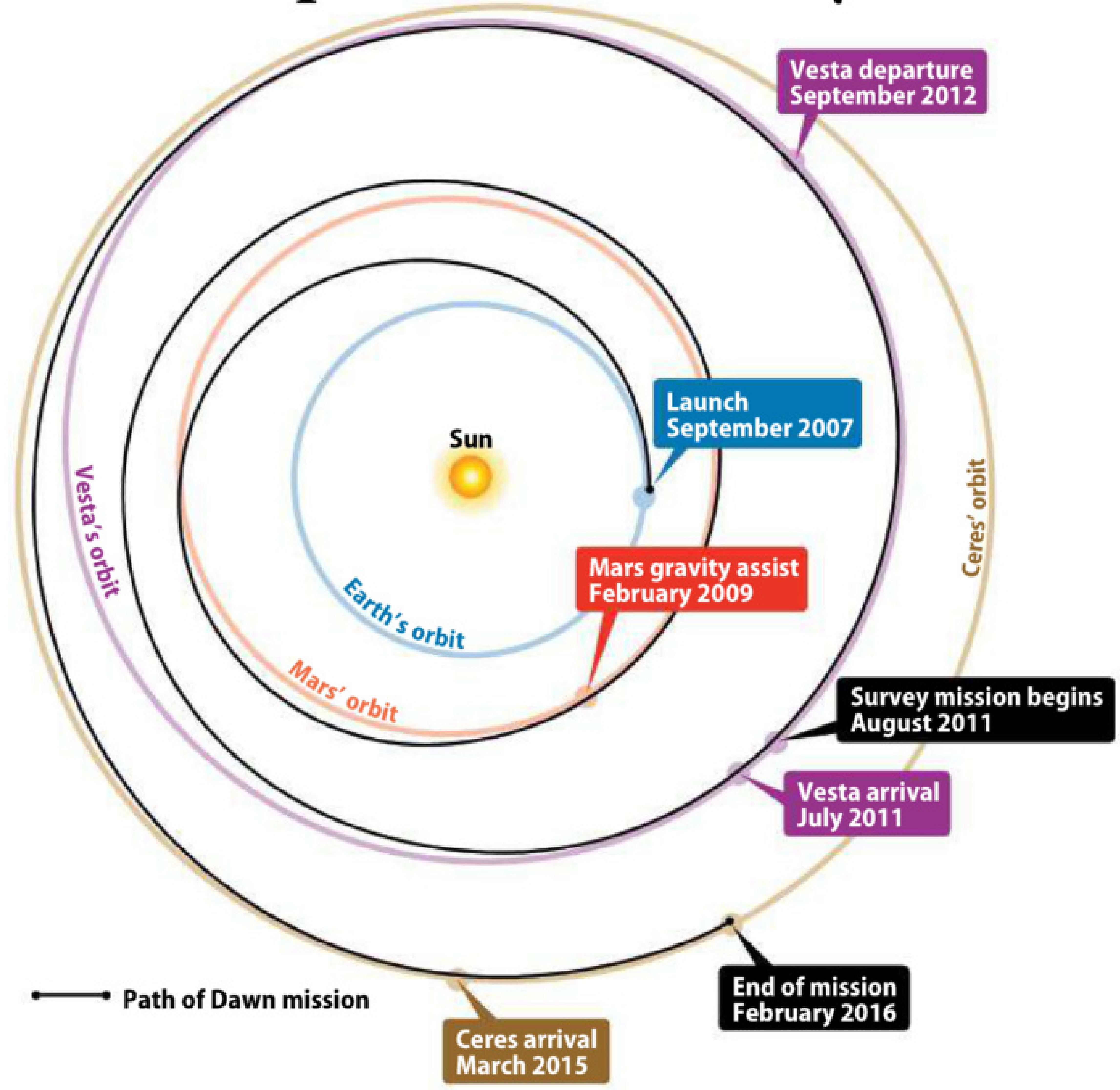
From what little information scientists have been able to gather, and from the blurry ideas they have of its finer points, they know Ceres is massive enough that its gravity pulled it into a sphere — like a planet's or a large moon's would. That circularity is the property that makes Ceres a dwarf planet, in a league with Pluto.

As astronomers learned more about Ceres from afar, its water-richness became apparent. Spectral analysis — even that done from Earth — shows hydrated minerals on the dusty surface, while the dwarf planet's low density suggests the mantle is composed largely of water ice. If that's true, says Jaumann, "Ceres is the largest innermost body with an icy crust and thus marks the transition between the inner rocky terrestrial solar system and the outer icy and gaseous solar system." It could tell us why our planet is different from the orbs around and beyond Jupiter.

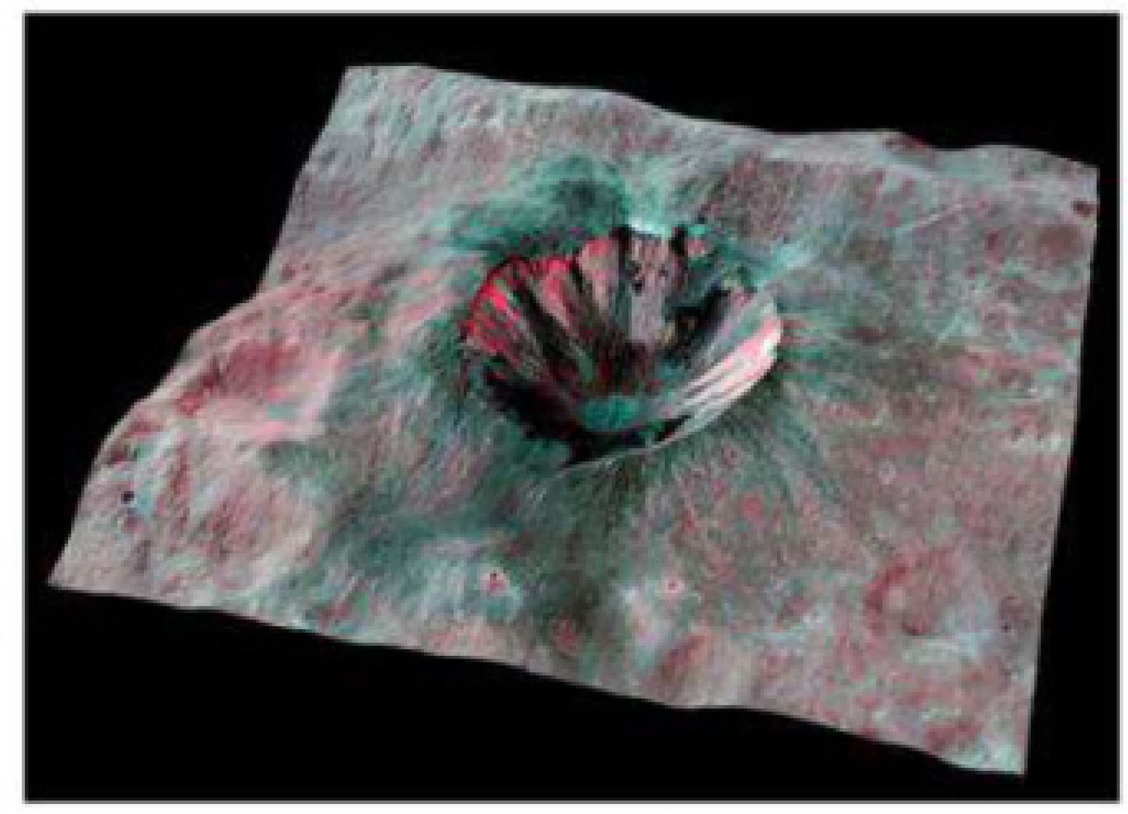
But there's no way to dig into Ceres' details without actually packing up and going there. This particular dwarf planet isn't giving anything away. "Meteorites are falling on Earth with origins all over the asteroid belt, but not one meteorite has been identified with Ceres," says Russell. "Ceres has been able to hide its secrets from us quite well. Just discovering how it has avoided doing that while its neighbor Vesta has been sending us messages very regularly — one in 16 meteorites comes from Vesta — is an important objective."

Dawn, much closer than Earth-based telescopes and radar, will be able to tell not

Dawn's trip across the solar system

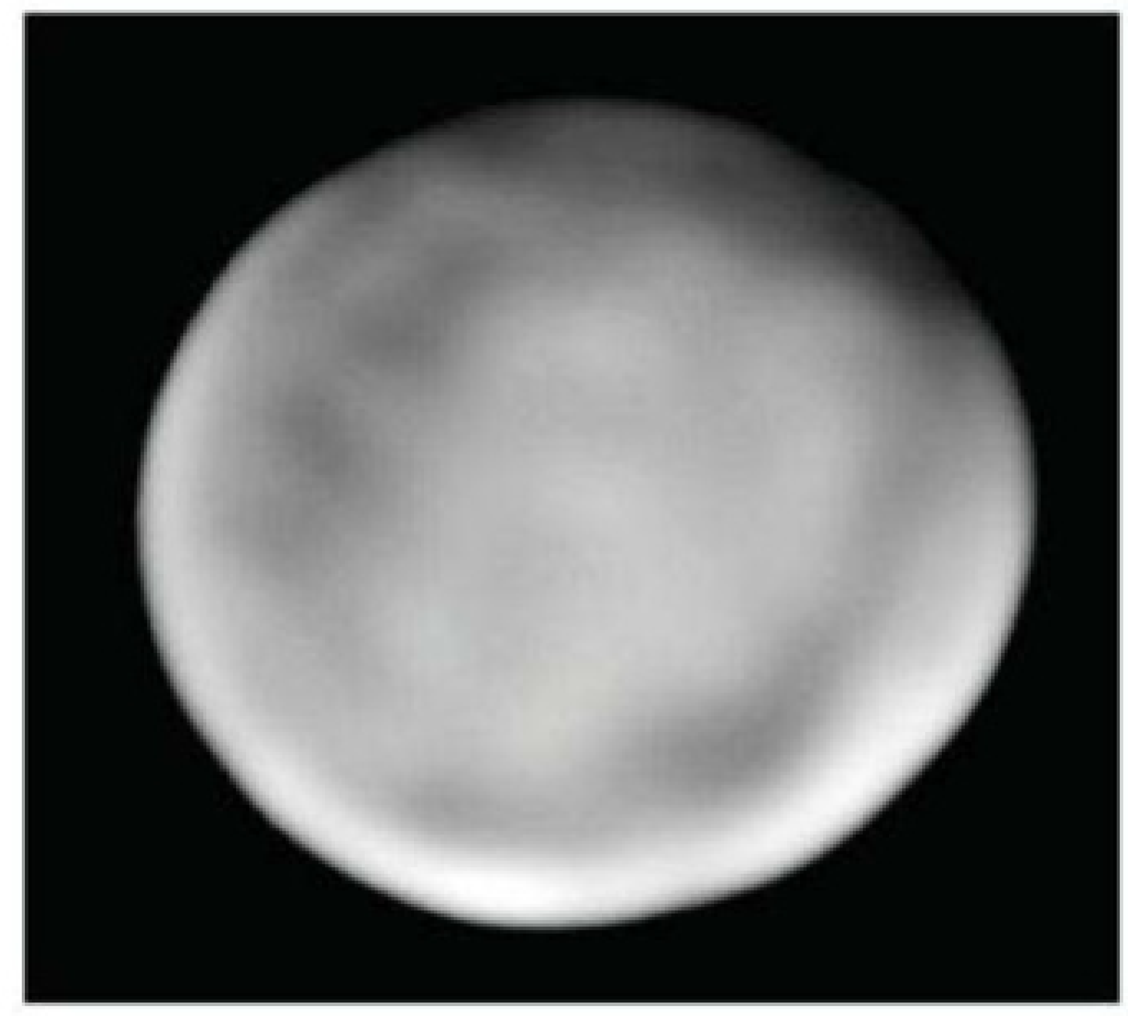


After launch, Dawn received a gravitational assist from Mars to attain its orbit around Vesta. After spending 14 months at Vesta, it began its path toward Ceres. The spacecraft will become the first man-made object to orbit two different bodies in the solar system. *ASTRONOMY*: ROEN KELLY, AFTER NASA



NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

In addition to light materials that impacts excavate from Vesta's interior, scientists have seen uncharacteristically dark materials. In Cornelia Crater, streaks of dark substance cover the surface. Scientists made this three-color view of the asteroid by wrapping images of the asteroid at three wavelengths around a topographical model of the area.



To date, this is the most resolved image of Ceres, which astronomers know is an icy, spherical world. When Dawn arrives in orbit around this dwarf planet, though, scientists will be able to discern its details. NASA/JPL-CALTECH/C. DUMAS

only how much water might be lurking on Ceres but also where it is and what other volatile compounds might pepper the dwarf planet. From this composition, scientists will be able to discern how, early in the solar system's history, life-sustaining water and organic carbon compounds came to be on rocky bodies in the first place and how they behaved once they got there.

One of Dawn's main goals is to see if a liquid ocean sloshes beneath Ceres' icy veneer. "This has not only profound implications for the different models of solar system formation but also for astrobiology research," De Sanctis says.

Other than that, scientists just plan to wait and see. "We do not know what else we will find on the surface," says De Sanctis. "Is there hydrothermal activity? Does it have a thin transient atmosphere? What is its subsurface structure?"

Surely, when the spacecraft arrives there and the first footage starts to pour in, astronomers like De Sanctis will come up with even more questions. Their answers will piece together Ceres' — and thus the solar system's, and thus Earth's — history.

"Our solar system is a complex assembly of planets, moons, small bodies, and material. This system hosts life," says Jaumann. "If we ask the question of the origin of life, we have to understand the environment. Earth is part of the solar system and thus part of this environment."

Story of life

Like the protoplanets tell the story of our planet, our solar system may help scientists with the narratives of other worlds, from how they formed to whether they may host life. "We live in an era in which we for the first time can explore planetary systems around other stars," says Russell. "The field is rife with speculation. … Our solar system is the only such planetary system that can provide ground-truth to test the myriad ideas that are flowing."

Missions like Dawn may appear to be limited in scope, visiting just two asteroids of the millions orbiting in just one solar system of hundreds of billions in one galaxy of potentially hundreds of billions in the universe. But concrete nearby objects are subject to the same physical laws as abstract distant ones. Investigating the easy-to-reach protoplanets and writing the biography of our solar system is like studying a toddler to understand how they develop into an adult human. While that toddler may not be identical to the millions of other toddlers on the planet, and those millions of toddlers will not all grow into identical adults, certain developments — walking, talking, getting taller, growing angst-ridden, first gaining and then losing muscle mass — hold true across the species. The same, scientists have found, is true of celestial objects. Dawn is changing our understanding not just of Ceres and Vesta, but also of the larger universe.

TO SEE DISCUSSIONS WITH DAWN SCIENTISTS, VISIT **www.Astronomy.com/toc.**

Comet ISON's final hurrah

Although this visitor from the distant Oort Cloud did not survive its late-November brush with the Sun, it provided observers with a memorable show in the weeks before. **by Richard Talcott**

Comet ISON (C/2012 S1) survived for more than 4.5 billion years in the frigid depths of the solar system, but it fizzled during its brief moment in the Sun. Through a combination of ISON's delicate makeup, the Sun's intense heat, and — most importantly — our star's powerful tidal forces, the comet's tiny nucleus disintegrated around perihelion, when it passed closest to the Sun on November 28 at a distance of 730,000 miles (1.16 million kilometers).

The end came with little warning. During late October and most of November, ISON behaved as if it would match, or at least approach, the brightness estimates astronomers had been touting since the comet returned to view in August. To be sure, there were hiccups along the way — comets rarely behave predictably. But ISON's icy nucleus, which measured no more than 0.8 mile (1.25km) across, spewed out greater amounts of gas and dust as it approached the Sun. Intermittent outbursts caused the comet's overall brightness to spike several times in the weeks before perihelion. The show delighted amateur astronomers and astroimagers alike.

The trek from Leo to Virgo

ISON spent all of October and the first days of November in Leo the Lion. During that period, the comet brightened from around 11th to 9th magnitude, or from a telescopic to a binocular object for observers with excellent skies. ISON passed from Leo into Virgo the Maiden on November 5 and within a week became an easy binocular target under good skies. At about the same time, the comet experienced its first major outburst. To learn how active a comet's nucleus is, astronomers study the rate at which it outgasses water, carbon dioxide, and other volatile molecules. Researchers reported a doubling of these liberated molecules November 8.

The fun was just beginning. ISON experienced a similar doubling on the 13th and another one on the 14th. The outbursts had a sudden and dramatic effect on the comet's observed luminosity — it climbed from approximately magnitude 8.0 to 5.5 (a factor of 10 in brightness) between the 12th and 14th. It finally had reached naked-eye visibility, at least for those viewing under the darkest skies, and urban observers were able to spot it through binoculars.

In mid-November, observers enjoyed the finest conjunction of ISON's long life. The

GERALD RHEMANN

Comet ISON's long, straight ion tail stretched all the way to the magnitude 5.6 star SAO 139175 in Virgo in this mid-November image. (8-inch Astro Systeme Austria Newtonian astrograph at f/3.6, FLI PL16070 CCD camera, LRGB image with exposures of 10, 3, 3, and 3 minutes, respectively, taken November 17, 2013, from Ebenwaldhöhe, Austria)

Comet ISON passed a colorful group of stars in south-central Leo during October's final week. (17-inch PlaneWave Instruments corrected Dall-Kirkham reflector, FLI PL6303e CCD camera, LRGB image with exposures of 16, 2, 2, and 2 minutes, respectively, taken October 27, 2013, at 11h31m UT) DAMIAN PEACH

Richard Talcott *is an* Astronomy *senior editor and author of* Teach Yourself Visually Astronomy *(Wiley Publishing, 2008).*

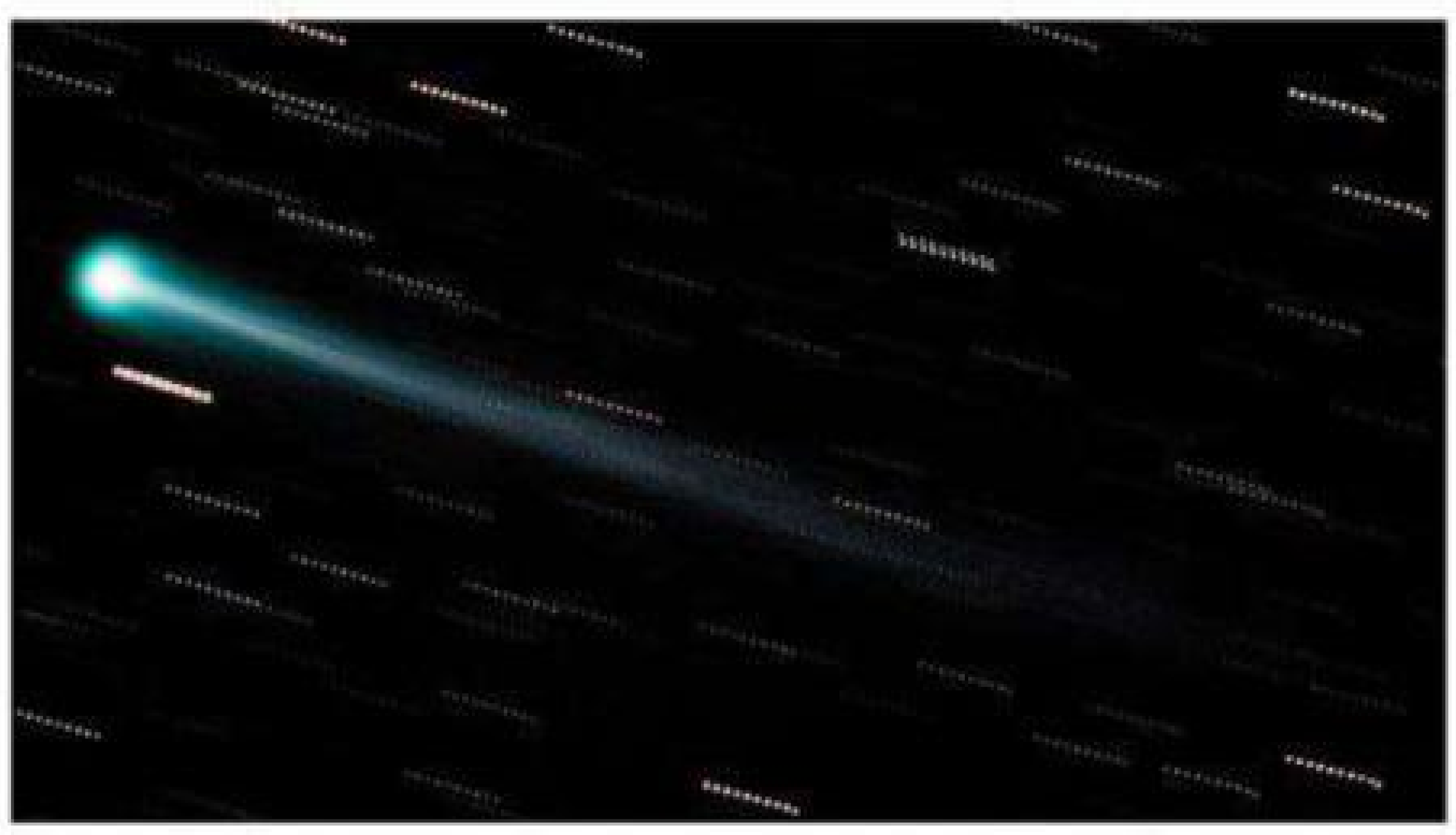
The sight of Comet ISON hanging above the horizon in the late-November twilight was a scene worth remembering, even though the celestial visitor fizzled out a week later. (Canon 5D Mark III DSLR, 70–300mm lens set at f/5.6, ISO 4000, 4-second exposure, taken November 22, 2013, at 6:04 A.M. Atlantic Standard Time from Port Medway, Nova Scotia) BARRY BURGESS

GERALD RHEMANN

Comet ISON appears upside down in this image taken from south of the equator just one week before the comet disintegrated. (12-inch Astro Systeme Austria Newtonian astrograph at f/3.8, FLI ML8300 CCD camera, LRGB image with exposures of 3, 2, 2, and 2 minutes, respectively, taken November 21, 2013, from Farm Tivoli, Namibia)

Comet ISON showed a distinct greenish color in many photos taken during late October and early November. (5.6-inch Telescope Engineering Company TEC-140 refractor at f/7, SBIG ST-10XME with CFW-10 and Astrodon filters, RGB image with 30 minutes of exposure each, taken November 2, 2013, from Anza Borrego Desert, California) MICHAEL CALIGIURI

Comet ISON passed near 1st-magnitude Spica in mid-November. Here, the comet's tail stretches all the way to Virgo's luminary more than 5° away. (3.2-inch Zeiss astrograph refractor at f/4.4, Canon XTi DSLR, ISO 400, 21 minutes total exposure, taken November 18, 2013, from Payson, Arizona) CHRIS SCHUR



◄ Comet ISON appears stationary relative to the moving stars of Virgo in this composite image. (4.7-inch Sky-Watcher 120ED refractor, Canon 60Da DSLR, ISO 2000, stack of eight 300-second images, taken November 14, 2013, from Calgary, Alberta) HARLAN THOMAS

comet closed to within 5° of Virgo's luminary, 1st-magnitude Spica, on the 16th and swept just 2° from the star on the 17th. Five degrees again separated the two objects the following day, when photographs showed ISON's tail stretching all the way to Spica.

The comet continued brightening as it approached the Sun. Astronomers reported another significant outburst November 16 and an even larger one on the 21st. Between the two of them, ISON's production of gas molecules increased by more than a factor of 10. Observers saw the comet shining at 4th magnitude, though their days of viewing were dwindling rapidly as ISON neared the Sun and appeared low in morning twilight.

A date with the Sun

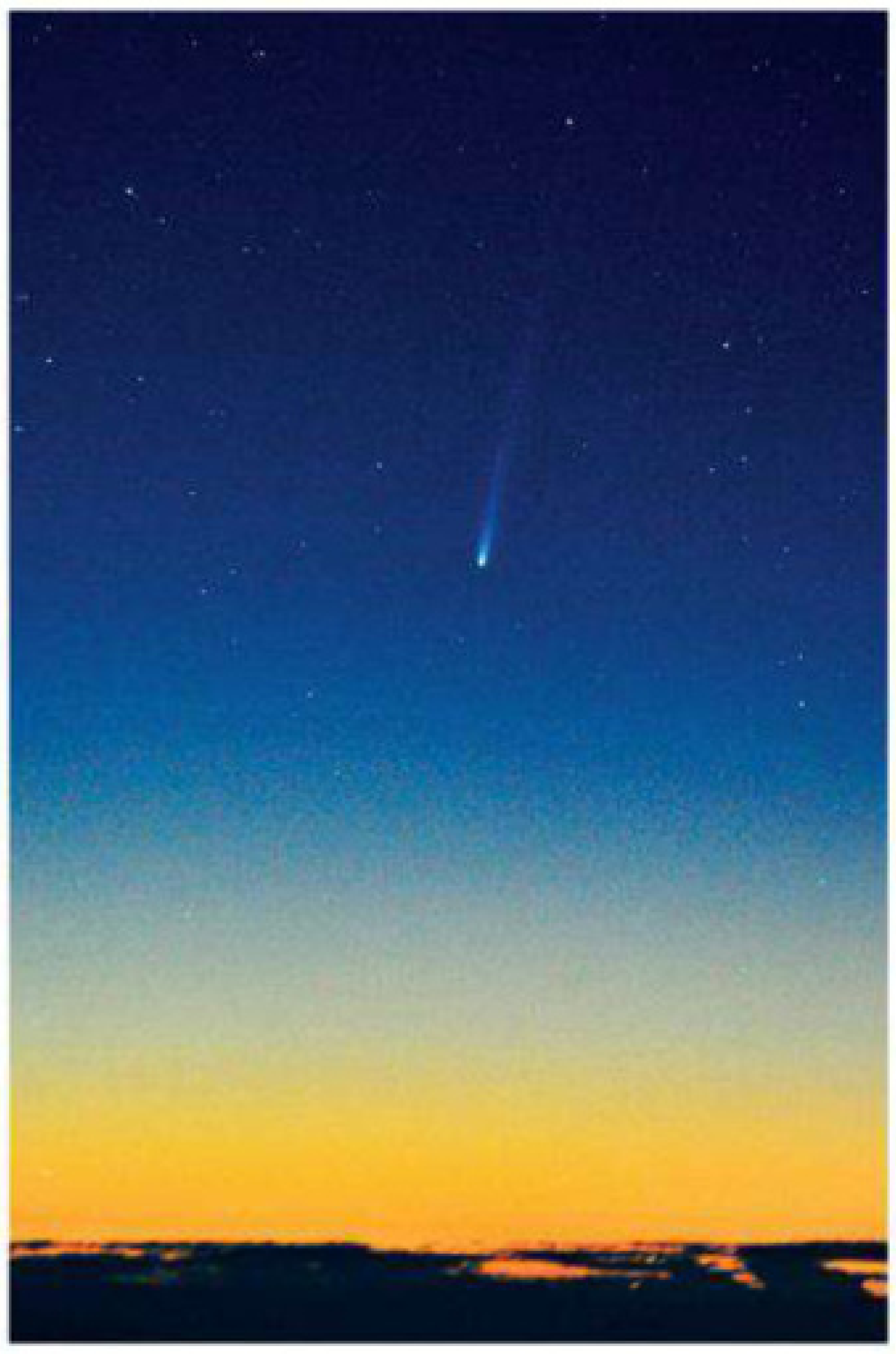
As the comet approached its November 28 perihelion, the best views came from two spacecraft: the Solar and Heliospheric Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO). ISON continued to brighten, peaking late on the North American evening of the 27th. It glowed then around magnitude –2.0, some 60 percent brighter than the night sky's most brilliant star, Sirius. Coronagraphs, instruments that block the Sun's disk and allow views of the solar corona and any nearby objects, aboard the two spacecraft then showed the comet as a bright point of light trailed by one distinct dust tail and a narrow dust streamer.

But ISON started to fade even before its closest approach to the Sun. The Solar Dynamics Observatory (SDO), which is equipped with the best cameras for close-up observations of our star and its surroundings, failed to see the comet at perihelion. And once ISON had moved far enough beyond the Sun that it could reappear in SOHO's coronagraphs, it was nowhere to be found.

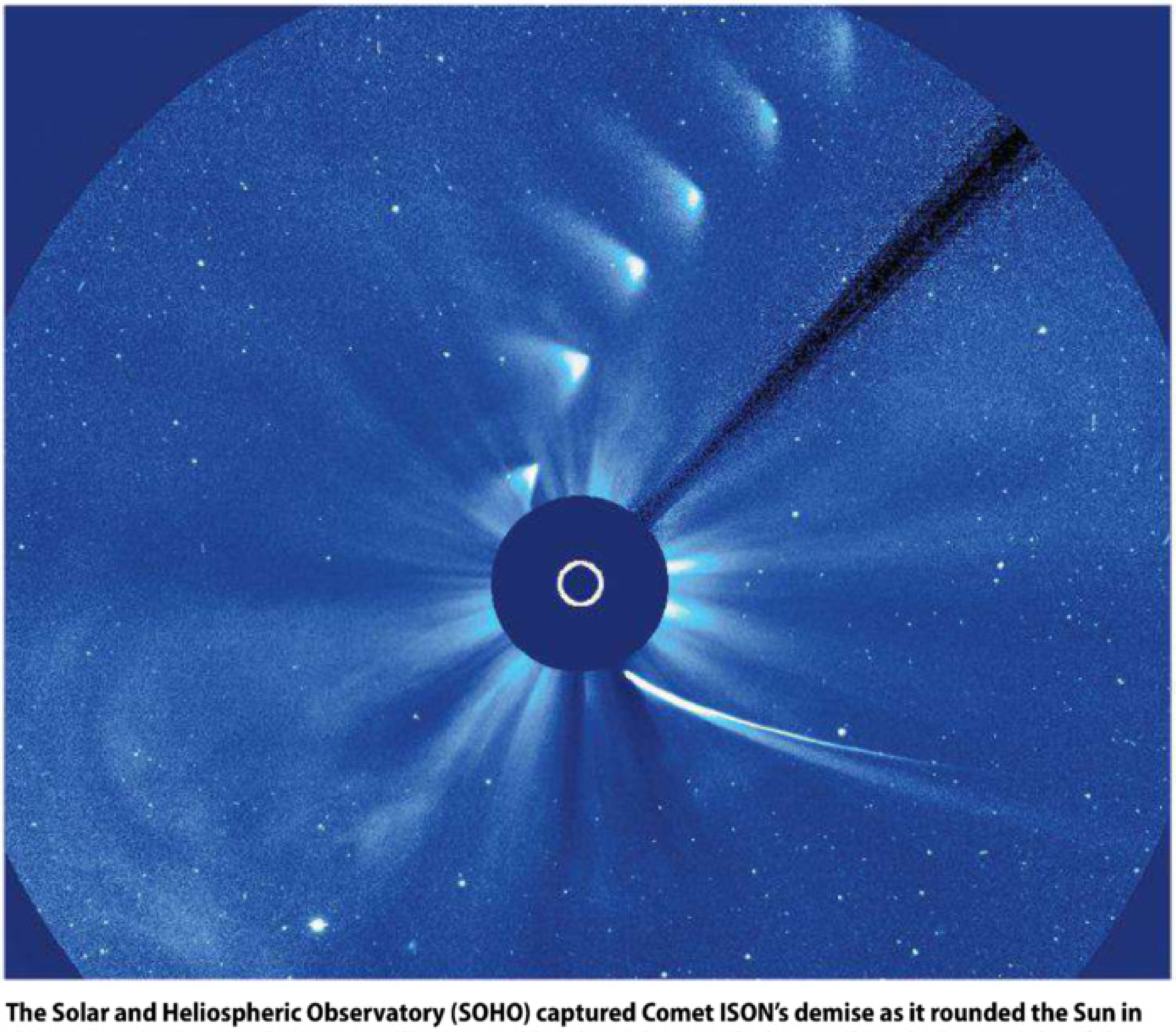
As astronomers began to write their post-mortems, however, the unpredictable comet rose from the dead like the legendary Phoenix. Some 24 hours after perihelion, SOHO captured images that showed a thin dusty tail and a diffuse central condensation that some interpreted as a small remnant of the comet's nucleus. But the revival soon petered out — by late November 29, the glow had faded to 6th magnitude.

The show amateur astronomers were hoping for in December failed to materialize. The tiny nucleus had dissipated, and the remaining dust cloud showed up only through sensitive telescopes equipped with CCD cameras. Even though ISON's saga has ended, however, astronomers will pore over their observations of this one-of-a-kind visitor for months, if not years.

Comet ISON's ion tail developed more than a half-dozen streamers as it approached the Sun in mid-November. (4.2-inch Takahashi FSQ-106 refractor, STL-11000 CCD camera, LRGB image with exposures of 10, 2, 2, and 2 minutes, respectively, taken November 15, 2013, at 12h08m UT) DAMIAN PEACH



Comet ISON brightened significantly in late November, growing luminous enough to see with naked eyes even in twilight under good conditions. (Nikon D700 DSLR, 80–200mm lens set at 135mm and f/5, ISO 1250, 10-second exposure, taken November 22, 2013, at 5:31 A.M. Hawaii Standard Time from the Kalahaku Overlook on Haleakala, Maui) ROB RATKOWSKI



The Solar and Heliospheric Observatory (SOHO) captured Comet ISON's demise as it rounded the Sun in this composite image. The comet still appeared bright and sported a long tail (to the lower right of the occulting disk that blocks the Sun from view) just before closest approach November 28. But ISON faded dramatically by the time its dusty remnant left the top of SOHO's field of view November 30. SOHO (ESA/NASA)

How I made my DREAM OBSERVATORY

The way this observer housed his telescope may give you some tips you can apply to your own project.

text and images by Bert Probst

During some 40 years in amateur astronomy, I have moved up from a 4-inch reflector to my present 8-inch Schmidt-Cassegrain telescope (SCT). In that time, I, like most observers, fantasized about someday having my telescope permanently mounted in a backyard observatory. Finally, after many nights of lugging my SCT, with its equatorial mount and heavy counterweight, out to my driveway, I bit the bullet and decided to build an observatory of my own near my house.

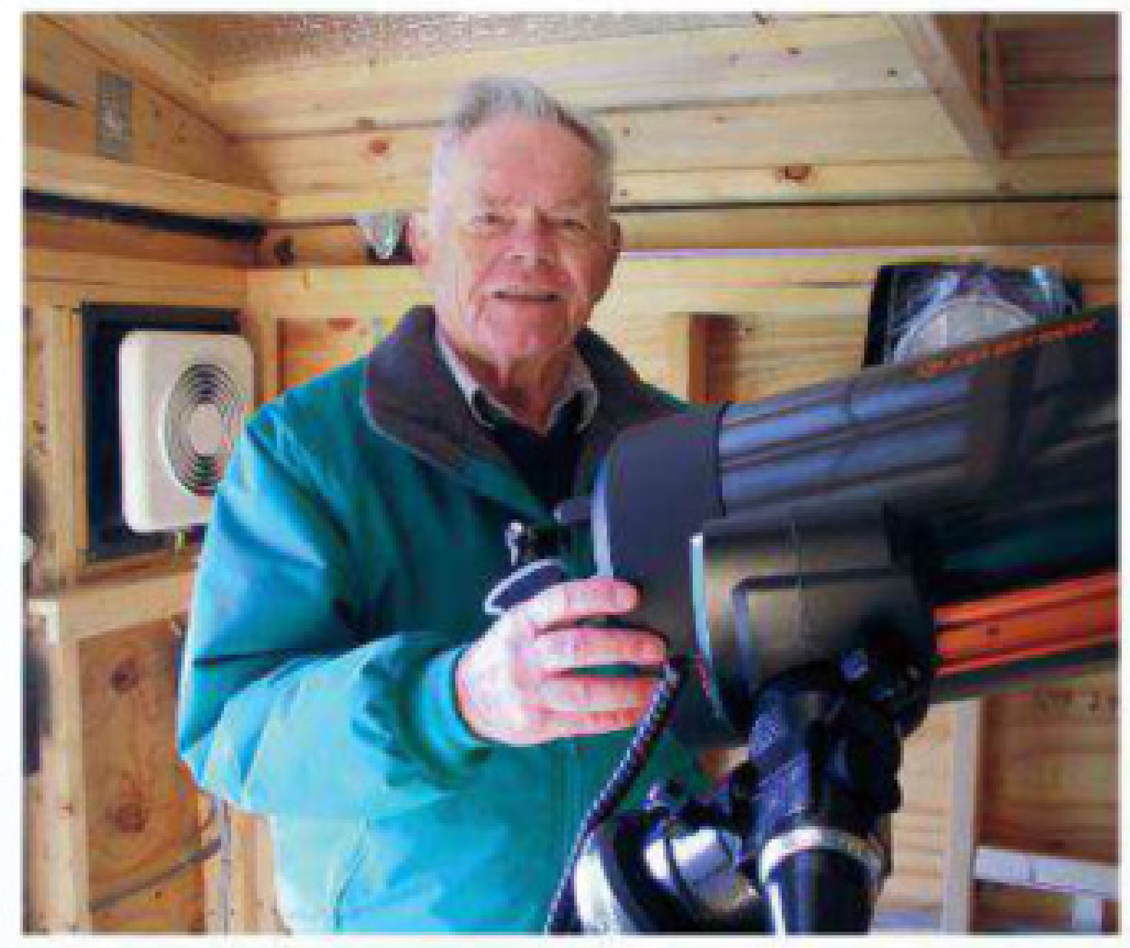
From this initial thought to the birth of my observatory was a long but fruitful process spanning three years at a cost of about $2,400. I had to make some tough decisions and trade-offs. But, looking back, it was challenging and fun, and the final product proved well worth the effort.

Bert Probst *is a retired NASA engineer who offers astronomy classes at his local library. You can send questions to him at bertski@juno.com.*

Roll-off or dome?

My first decision was whether to go with a roll-off roof or a dome. I chose the former for several reasons. First, a roll-off roof is simpler to design and less expensive to build. Also, while I'm observing, I prefer to see the entire sky rather than the limited view through a dome slit.

In making my plans, I consulted many sources. I also touched base with others who had built such observatories. The study and personal contacts I made along the way were invaluable and, I believe, prevented many false starts. My most important finding was that a roll-off roof requires a clearance between the roof and walls to allow the roof to move freely during opening and closing. This was of some concern to me because of my location.



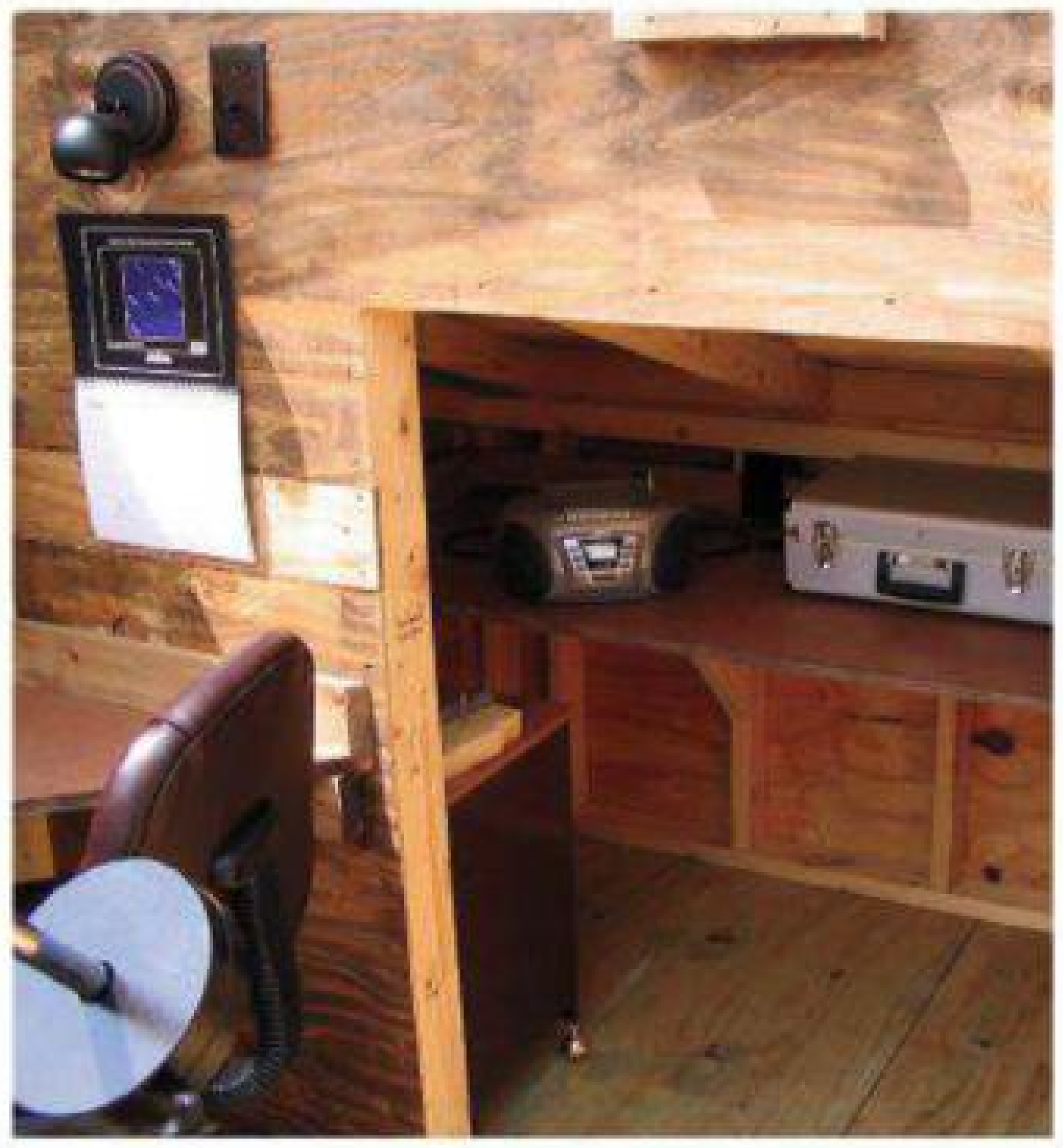
The author stands inside his completed roll-off roof observatory next to his 8-inch Schmidt-Cassegrain telescope.

My observing site is in a rural setting in western New York, so I was worried that small birds, wasps, bees, bats, and other critters might enter through the gap and take up residence. I'm sure any amateur astronomer can share my fear of entering the observatory for a fine night of viewing the heavens only to find a wasp nest attached to my scope!

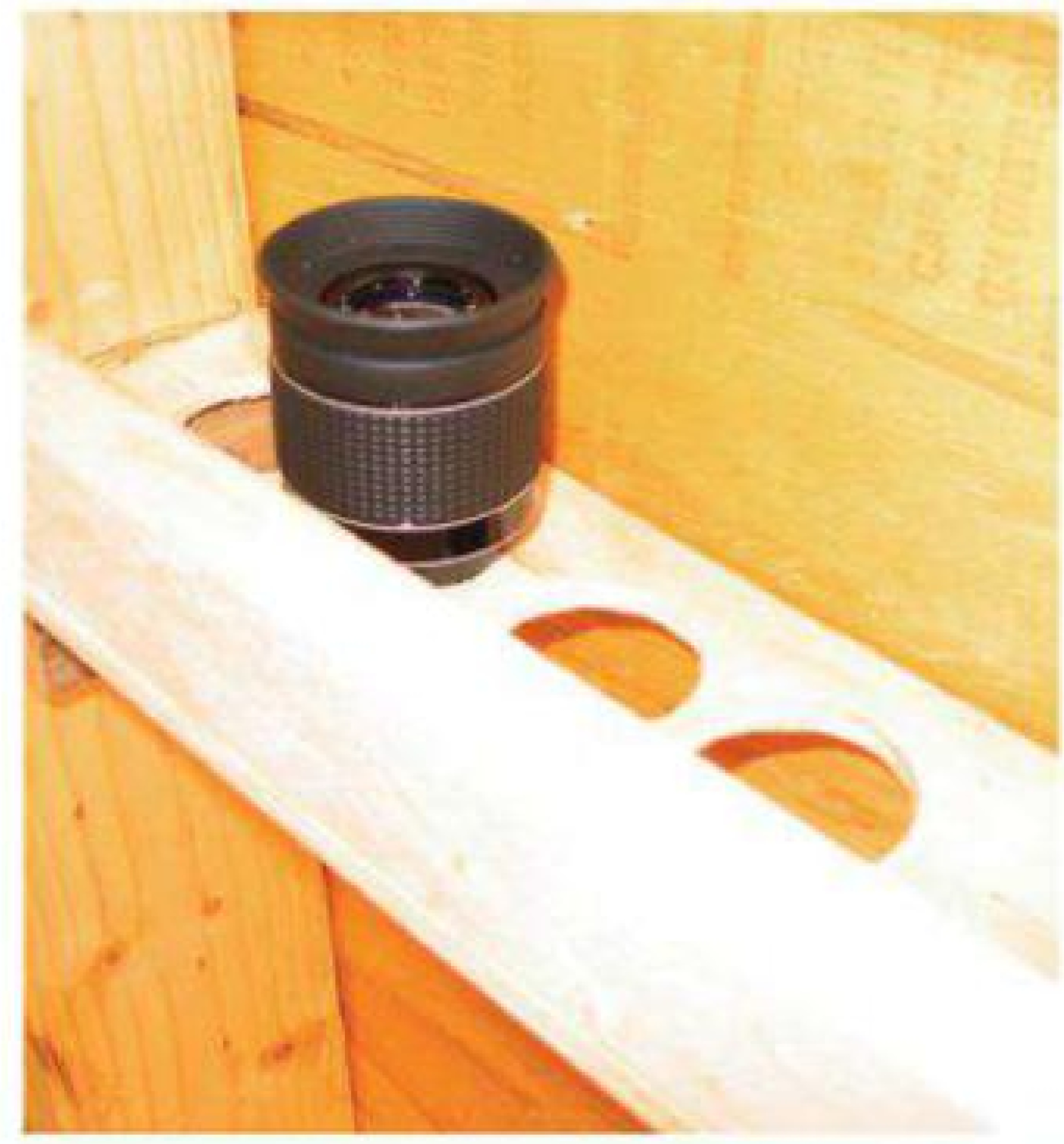
So, I set about creating a

The author constructed his observatory with two parts. The telescope sits in the main section (right), which measures 8 feet by 8 feet (2.4 meters square). Adjoining it is an 8-foot by 4-foot warm room, which the roof slides over.

The author constructed a pair of steel plates with four bolts to mate his telescope's mount to the permanent pier. The adjustments allow him to level and secure the mount.



The author configured his observatory's warm room with lots of storage space. It also contains an 8-foot-long by 30-inch-wide desk, a portable electric heater, and a CD player.



The author did not install an interior wall, a decision that left the 2x4 boards that support the walls exposed. This allows him to use the space for storage and shelves, as in the case of this eyepiece holder.

design that would provide adequate clearance for mobility and at the same time ensure a critter-proof seal between roof and walls when closed. I accomplished this, and it was the most important innovation in my observatory. More on this later.

Interior design

One consideration in any observatory is locating it with respect to unfriendly lights and obstructions such as buildings and trees. Next is the permanent pier for the telescope. Mine is an 8-inch-diameter (20 centimeters) well casing sunk 8.5 feet (2.6 meters) into the ground and filled with concrete. This provides stability to the scope and sits well below frost level.

Cast into the pier's top are four ½-inch anchor bolts that attach to the equatorial mount. To span the distance between pier and mount, the assembly consists of a ¼-inch-thick steel plate and four ½-inch bolts. The bottom plate accepts the four bolts from the pier, and the top plate accommodates the bolt from the mount. Three nuts anchor the top of each bolt — one atop the upper plate and two below it. This system allows for leveling the equatorial mount and securing it when level.

Once the pier was in place, it was time to put a building around it. My observatory is 8 feet square (2.4m square), with an 8-foot by 4-foot (2.4m by 1.2m) warm room. It is of standard construction, using 2x4 boards with wall studs on 16-inch centers. The studs are bare, with no internal dry wall. I read that mice only nest in confined spaces, so I decided to leave the studs open.

I placed a dimmable red rope light behind the perimeter rail, which provides

The dips in the U-channels were one of the author's innovations, and they provide a tight seal between the roof and the walls. These two images show the same caster. On the left, the roof is about to close and the caster is on the track's flat part. The right picture shows the caster in the dip and the roof closed.

indirect lighting without destroying my night vision. When necessary, I can retreat to the warm room, which contains a portable electric heater.

Also in the warm room is a 30-inch by 8-foot (76cm by 2.4m) desktop for charts. This flat surface and the floor space below it provide what, to this date, has been adequate storage space. I also have a CD player to furnish some musical background during my time with the stars.

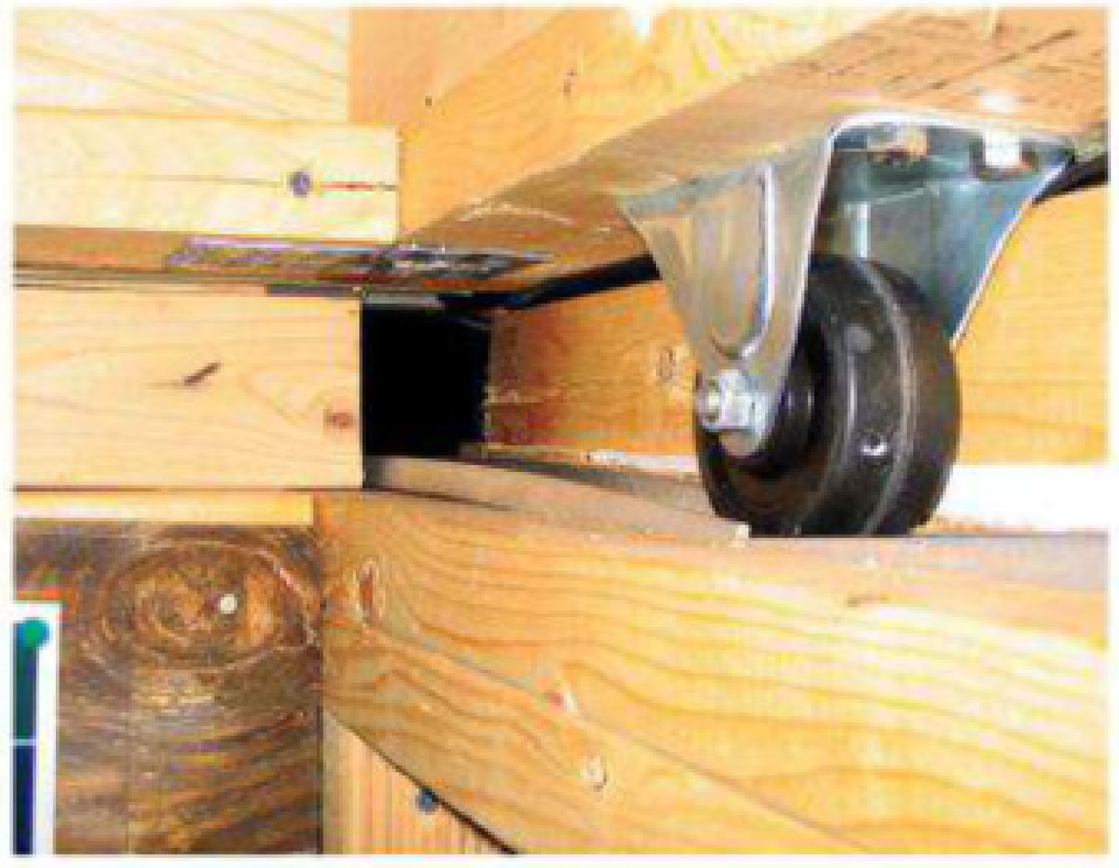
The building sits on six 4-inch by 6-inch (10cm by 15cm) posts sunk well below the frost line. The site slopes slightly (4°) to the south. The floor sits at least 8 inches (20cm) above grade to allow ample clearance for a heavy rain to flow under the building.

A comment I often heard in the planning stage was, "Be sure to have adequate electrical outlets." I installed 16 — 10 in the observing area and six in the warm room. I divided these into five circuits fed from the circuit breaker box above a small triangular writing space. This little desk is handy for making notes at the scope.

To avoid having trees block the horizon, the observatory lies 300 feet (91 meters) south of the author's house. He had to dig a ditch in order to run a power line between the two buildings.

I also installed a high-volume exhaust fan and wired it so I can turn it on from the house (about 300 feet [91m] to the south). Starting it up well in advance of a summer observing session lets the telescope cool before I arrive. I built into the observatory a roof ridge vent and two floor vents, which provide lots of natural convection. Because of them, the interior never gets too hot.

So the roof won't blow away during windstorms, the author connects three hold-down bolts after each viewing session. Two of them secure the roof to the observatory's front wall, and an additional one connects the roof to the rear wall.



These two pictures taken with the observatory's roof closed show the small opening above one of the U-channels (left) and one of the plugs the author made to seal that gap.

The all-important roof

Next, I had to consider how to construct the roll-off roof. I decided to support my roof on four 3-inch (7.6cm) casters, one near each corner. These casters ride in aluminum U-channels mounted on top of the east and west walls.

To achieve the roof-to-wall seal, I bent four dips — one for each caster — about 0.5-inch (1.3cm) deep into the U-channels. I positioned them so that when the casters reach the bottom of the dip, the front and rear of the roof sit directly over the front and rear walls. So, as the roof drops into these dips, it seals with the walls.

I fitted all surfaces with heavy-duty weather stripping. When I open the roof, it raises as the casters ride up the slight incline in the U-channels. This does not take a great deal of muscle power. And once the casters are out of the dips, the roof moves horizontally with ease. This design has worked well for two years. During that time, no critters have invaded the building.

I had to address two more roof issues. When it is closed, a gap still remains at its rear over each U-channel. After I close the roof, I fill these gaps by hand with wooden plugs that provide a tight seal.

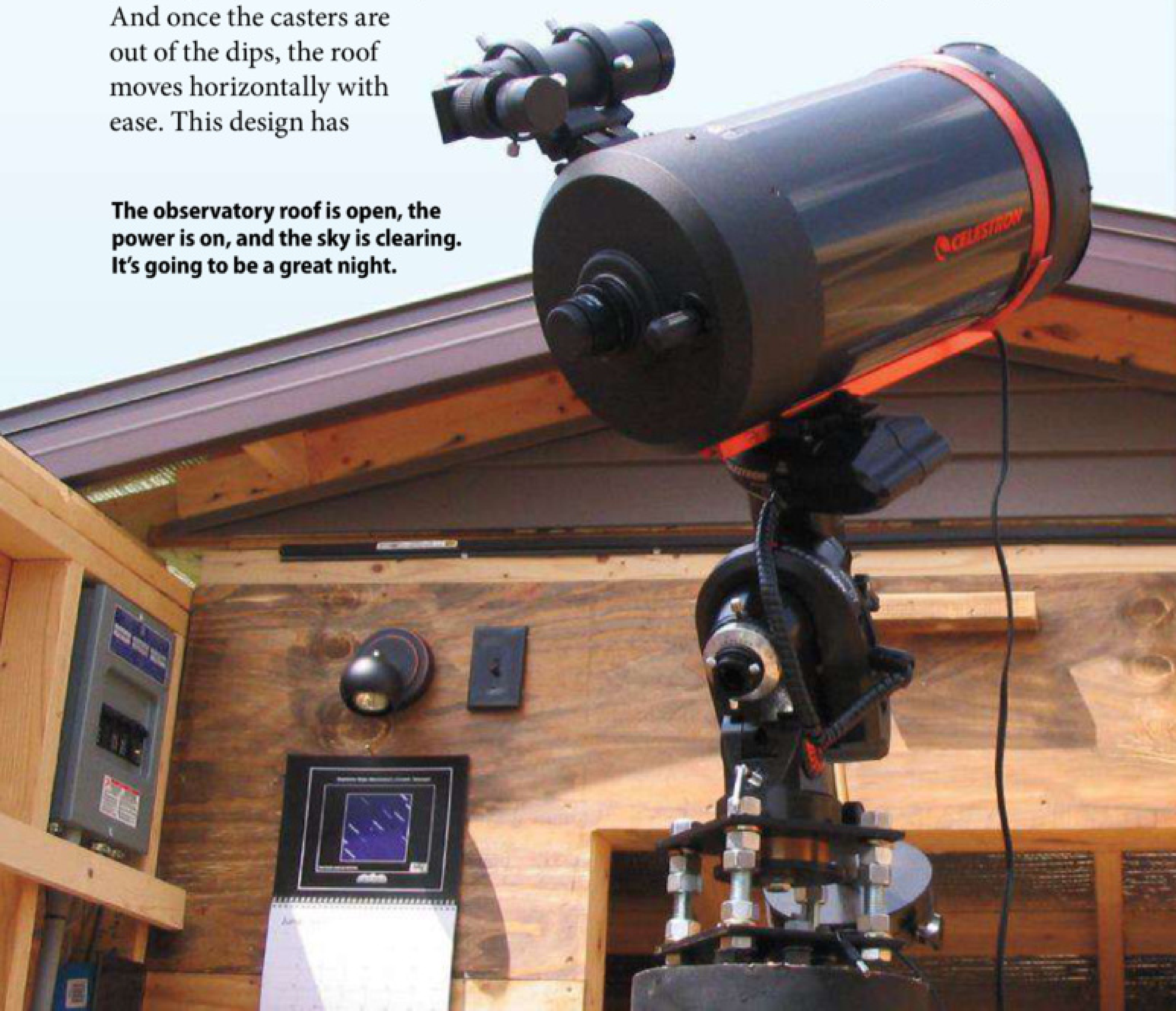
Good thing, too, because my site sits on a ridge 2,300 feet (610m) above sea level and can experience severe winds. I initially thought the roof might be too light to hold it down in a storm. So, I place ½-inch bolts about 9 inches (23cm) long through mated holes in the top of the front and rear walls and the bottom of the roof. Two in front and one in back provide a secure lockdown.

A dream come true

The observatory has met all of my expectations, and the changes and upgrades I added make it a joy to use. If I were to do it over again, I would expand the size from 8 feet square to 10 feet square (3m square). The current size is quite adequate when I am observing alone, but a larger space would be more comfortable when I am showing the sky's wonders to visitors.

I want to express my thanks to two key individuals: Dug Stein, the carpenter, and Rudy LaBelle, who served as project manager and consultant. Both men contributed many helpful suggestions and ideas.

I thoroughly enjoy my observatory now that the hassle of nightly setup and teardown is a distant memory. Also, the convenience makes sharing my hobby with friends easier and more enjoyable.



The observatory roof is open, the power is on, and the sky is clearing. It's going to be a great night.

In addition to a long desk in the observatory's warm room, the author installed a small triangular desk near the telescope. Note the circuit breaker panel just above the desk.

Run a globular cluster marathon

M22 in Sagittarius glows at magnitude 5.2. It lies in a rich Milky Way star field. BERNHARD HUBL

How many globulars can you see in a single night? Our intrepid writer put himself to the test. **by Tom Polakis**

During the last week of March, you can see all 109 targets in Charles Messier's famous catalog of deep-sky objects in a single night. Since 1981, amateur astronomers in Arizona have enjoyed a large Messier marathon gathering with observing all 109 as their goal.

Having attained a perfect score at several of these events, I thought about a more challenging all-night project that would capture the marathon's spirit. Recalling that the Milky Way contains roughly 150 known globular clusters, I was curious as to how many of those I could see on the night of the Messier marathon.

Globular marathons are not a common pursuit, but amateurs have done them. In 2005, Hawaii amateur Lance Humphreys observed 101 of them from Bolivia in one night, mostly using a 22-inch telescope with a go-to drive.

Five years earlier, Australian observer Les Dalrymple found 119 globular clusters in a single night with his 12½-inch Newtonian reflector. During my planning, I would quickly learn that their Southern Hemisphere locations gave these observers a huge advantage. How would I fare from 33° north of the equator?

You must have a plan

As is true with the Messier marathon, a well-prepared observing strategy is the key to success. Because the pace would be frenetic in the late morning hours, the sequence required careful attention. Desktop planetarium software proved to be invaluable in planning the observations.

Also, many globular clusters lie on the edge of visibility even through large telescopes, so having a plot of the telescopic star fields near the eyepiece is essential. For these faint targets, I used the Digitized Sky Survey to create finder charts.

Two-thirds of all globulars lie within 45° of the Milky Way's center, which sits on the meridian (the imaginary north-south line that passes through the overhead point) at dawn in late March. Unlike the relatively steady pace of the Messier marathon, a globular marathon at this time is a leisurely stroll for the first seven hours followed by frantic observing for the last three.

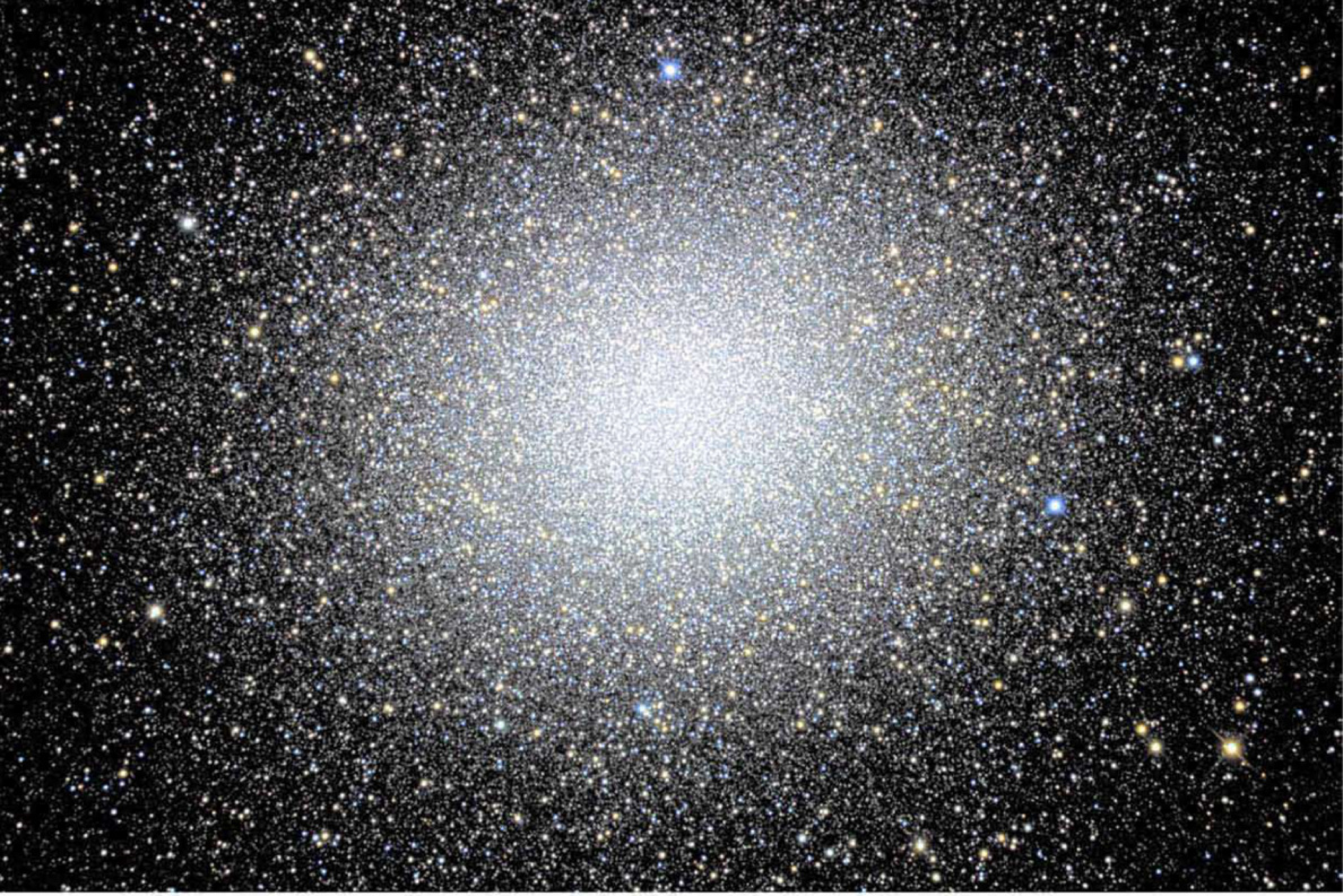
At Southern Hemisphere latitudes, the galactic center passes overhead, so an observer can take several minutes to make each observation. In the north, however, amateur astronomers have to maintain a rate at least double that — about one per minute before the sky brightens.

An easy start

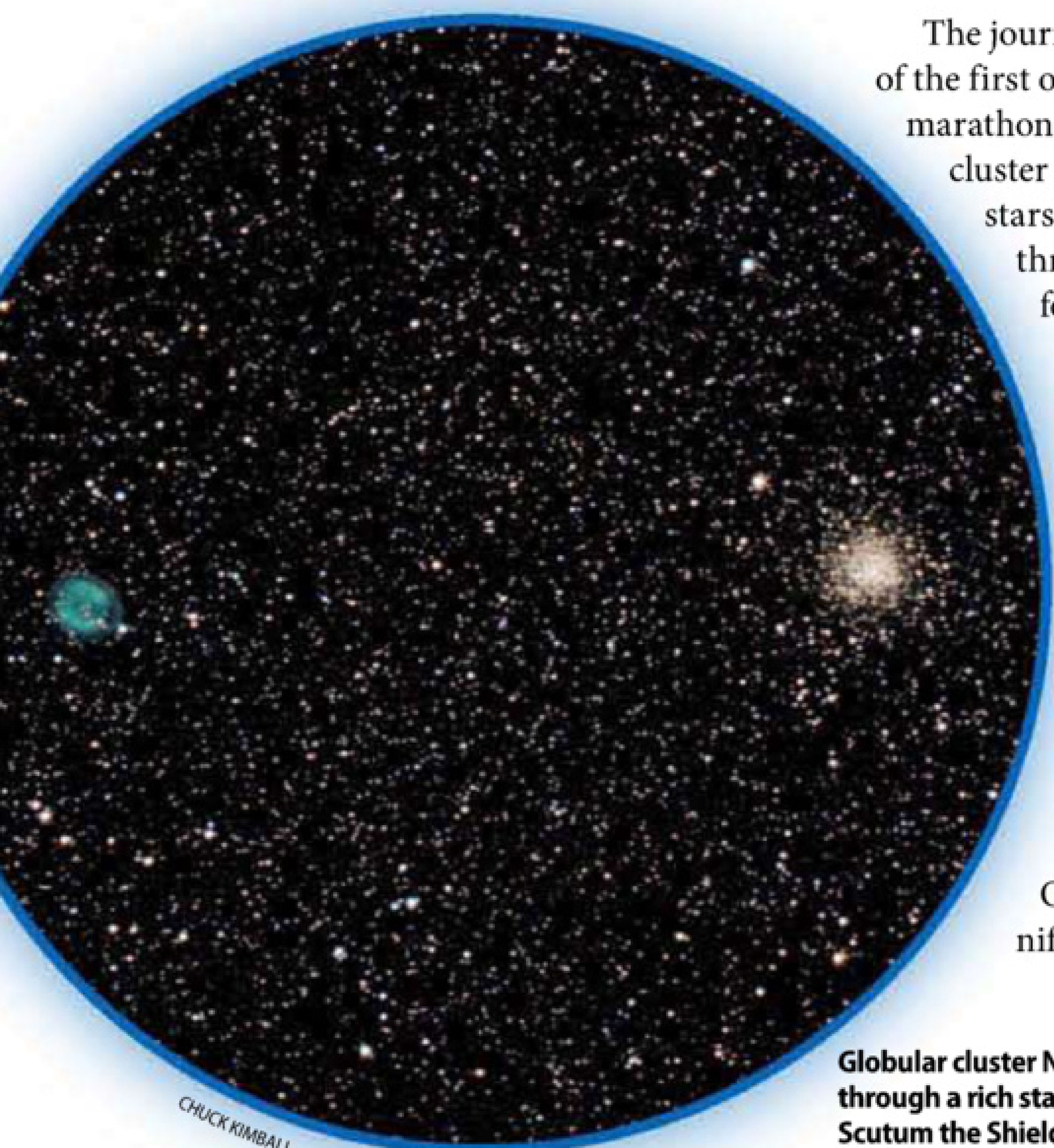
The 2012 All-Arizona Messier Marathon commenced March 24 under clear skies at a low-desert site 90 miles (145 kilometers) west of Phoenix. No fewer than 130 globular clusters were available on this night, but keeping in the spirit of the Messier marathon, I trimmed the list to 109 by eliminating the faintest ones.

I set up 18- and 10-inch Dobsonian-mounted Newtonian reflectors so that I could compare the views. In each, I put an eyepiece yielding a roughly 1°-wide field of view. Both instruments have finder scopes, but neither has motorized pointing or electronic setting circles.

Tom Polakis *is an* Astronomy *contributing editor who has logged thousands of hours observing all types of celestial objects.*



Omega Centauri (NGC 5139) is the sky's brightest globular cluster at magnitude 3.9. If it rises even 5° above the horizon at your site, you won't have trouble spotting it. This object has a diameter of nearly 1°, which means it covers more than three times as much sky as the Full Moon. DANIEL VERSCHATSE



Globular cluster NGC 6712 (right) floats through a rich star field in the constellation Scutum the Shield. Planetary nebula IC 1295 (left) lies only 0.4° east-southeast of the globular. CHUCK KIMBALL

The journey began at dusk with one of the first objects in everybody's Messier marathon sequence, M79. This bright cluster in Lepus showed about 50 stars surrounding a bright core through the 18-inch. Easily found by hopping off a pair of naked-eye pointer stars, it was an encouraging way to begin the marathon.

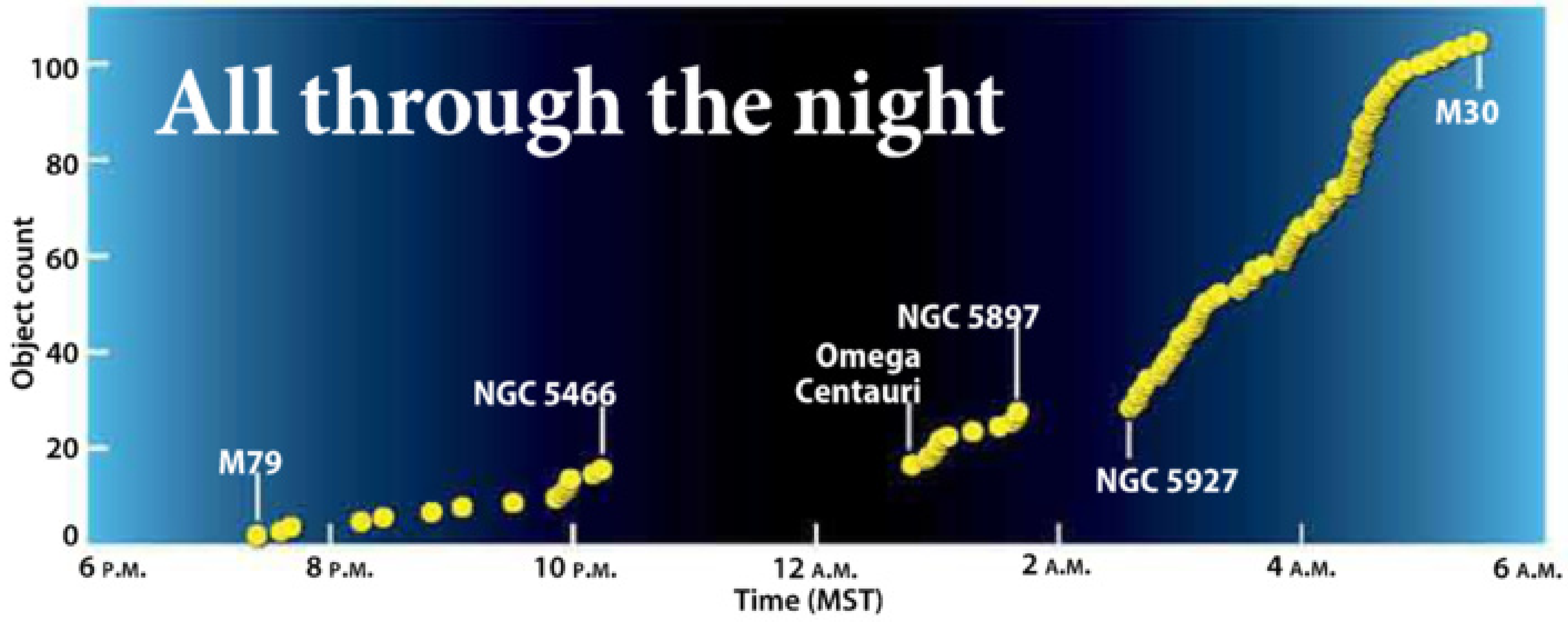
After knocking off NGC 1851 and NGC 2298, two more bright southerly clusters, it was on to the Eridanus globular (ESO 551–SC 01), which astronomers discovered in 1977. This would be the first of many difficult observations. Only by bumping up the magnification in the 18-inch to 160x could I see the 1'-wide clump in a bland star field. The luxury of changing eyepieces was something I had only during the evening hours, before the jog turned into a sprint.

Up next were several Palomar globular clusters, again well away from our galaxy's center. In the 1950s, astronomers discovered 15 notoriously difficult to detect globulars on Palomar Observatory Sky Survey plates. Palomar 2, located at the Auriga-Taurus border, was the easiest of the evening trio, showing a broadly concentrated haze with no stars.

The most northerly globular cluster, Palomar 1, is faint. Even through my 18-inch telescope, I saw this smudge only 25 percent of the time in a few minutes of looking. Likewise, Palomar 4 required a long stare to even confirm. At this point in the marathon, I realized that detecting the faintest globulars, not star-hopping to the locations of those objects, was going to be the hardest part.

A break, and then part 2

After the first three hours, I realized that I had seen only 15 clusters yet I was on



The author kept track of when he made his observations during the globular cluster marathon. Plan your observing session accordingly. *ASTRONOMY*: ROEN KELLY, AFTER TOM POLAKIS

ANTHONY AYIOMAMITIS

Palomar 2 lies in the direction opposite the galactic center. It glows faintly at magnitude 13.0 as it floats in the Milky Way's halo, some 90,000 light-years from Earth in the constellation Auriga.

schedule. Another three hours would pass before the next batch would rise high enough to pursue. This was a good period to either walk around the observing field or nap. Knowing what was in store after midnight, I chose to nap.

By 1 A.M., the most spectacular globular cluster in the sky, Omega Centauri (NGC 5139), was well-placed. Its appearance presented a great way for me to resume the marathon. During the next hour, I logged another 12 globulars. Not bad, but that brought me to less than one-quarter of the way to my goal. This batch contained showpieces including M5, M13, and M92. It also included a difficult catch in the form of Palomar 14, which I described as "a 2'-wide haze, barely detectable."

The sprint began at 2:30 A.M. — a scant three hours before dawn. I would have to find and observe one globular cluster every two minutes to reach 109. Luckily, 22 bright Messier objects lay ahead. On the faint end of the scale were dim NGC clusters and objects not even in the NGC, with obscure designations from catalogs such as "Terzan" and "Tonantzintla."

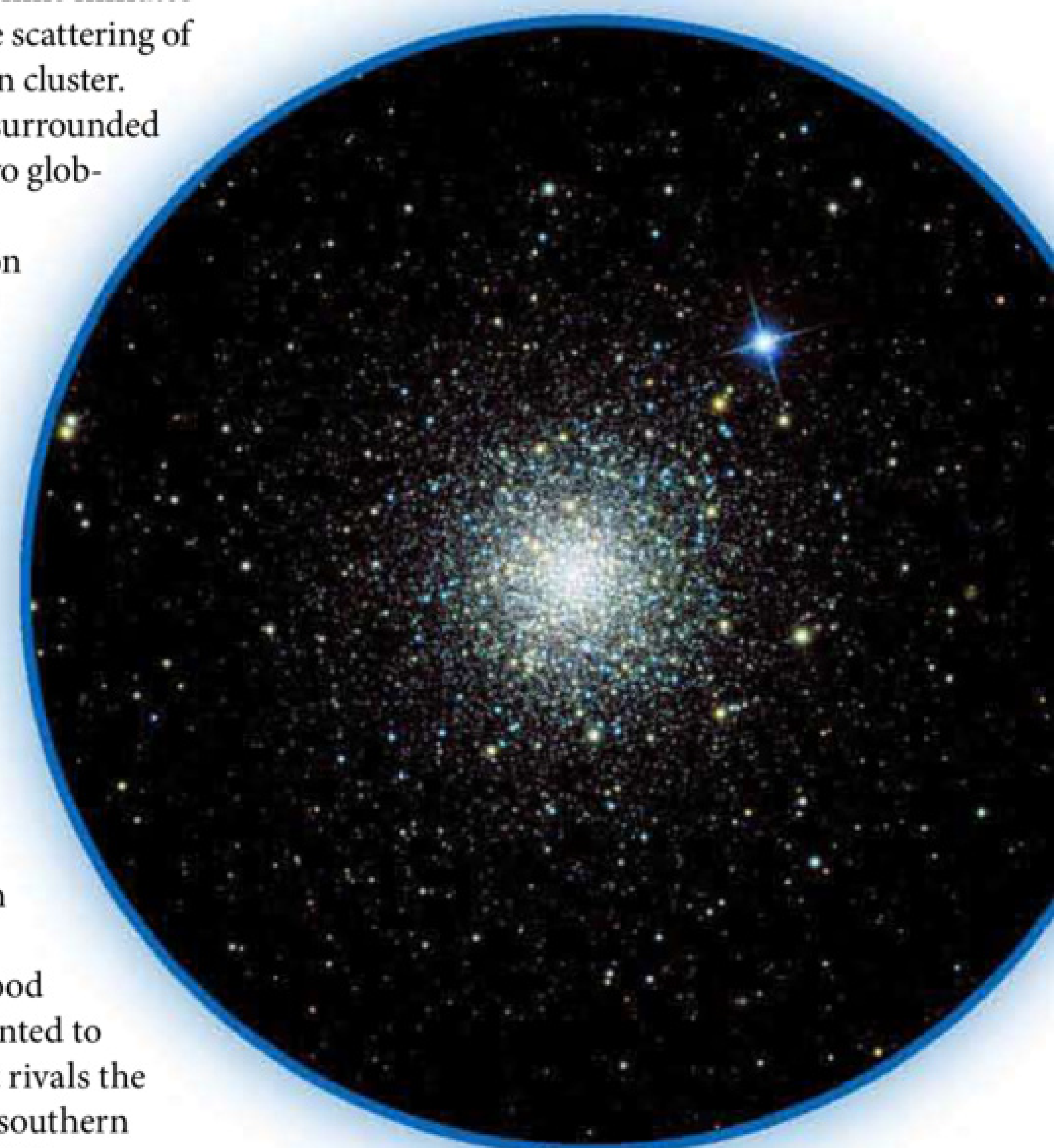
To complete the marathon, maintaining the object-per-minute rate is important. That means knowing when it's time to skip over an object you can't see. I learned this the hard way after losing nearly 10 minutes in a futile search for NGC 6540. I was certain that it was in the field, and NGC objects are generally bright enough through an 18-inch, so how could I not see it?

I learned from my observing notes that I had spotted it a decade earlier, describing it as only 1' across and completely buried in a rich star field. Similarly, I killed eight minutes near the end of the marathon before finally bagging Haute-Provence 1.

While I sensed the pressure during these three hours, I also enjoyed the reward of quickly surveying the diversity in the visual appearance of globular clusters. M14 revealed hundreds of faint stars against a bright background haze. Only nine minutes later, I was viewing M4, a loose scattering of bright stars resembling an open cluster. NGC 6356 had a blazing core surrounded by well-resolved faint stars. Two globulars later, NGC 6355 showed almost no central concentration with only a hint of resolution. Then there were clusters in magnificent fields, such as NGC 6712 behind the Scutum Star Cloud. And it was hard not to pause to admire the pairing of NGC 6441 with the orange variable star G Scorpii.

The most southerly globular on the list, NGC 6397, culminated (attained its highest position) less than 4° above the southern horizon from the marathon site. The observing window when it stood above the horizon haze amounted to less than a half-hour. While it rivals the Hercules Cluster (M13) from southern sites, its splendor dropped to little more than a brightening in the sky.

Likewise for NGC 6584, which crossed the meridian a half-hour later. It would be the penultimate observation in the globular marathon. With the sky brightening rapidly an hour before sunrise, the marathon ended appropriately with a successful observation of M30. Many others on the observing field were pursuing it as the last object in the Messier marathon.



M30 in the constellation Capricornus is the final object in both the author's globular cluster marathon and the Messier marathon. It shines at magnitude 6.9. DANIEL VERSCHATSE

A well-run race

Exhausted but exhilarated, I had tallied 105 globular cluster observations in a single night. They ranged from the faintest recognizable hazes to star-studded spheres showing hundreds of stars. Collections of stars between 7,000 and 70,000 light-years away came into the view of my telescopes. This experience left me with one thought: I have to go back and observe every one of these globular clusters during the coming year at a much more sensible pace.

DOWNLOAD THE AUTHOR'S ENTIRE LIST OF 109 OBJECTS ONLINE AT **www.Astronomy.com/toc.**

Sketch the Messier objects in one night

If you're looking for a new observing challenge, try capturing all 109 objects in Messier's catalog on paper.

text and images by Erika Rix

If the thought of sketching the Messier marathon makes you gasp, you're in good company. I did as well when I heard that fellow observer Jeremy Perez had masterfully sketched 104 of the 109 Messier objects during the night of the 2009 All Arizona Messier Marathon. Intrigued, I had to try it for myself. In the end, the experience left me not only exhilarated but also with a tremendous sense of accomplishment after sketching 103 Messier objects on my first run.

A little history

The Messier marathon is an endurance race to locate as many of the 109 Messier objects as possible during the course of a single night. It all started when, in 1754, French comet hunter Charles Messier noted a stationary comet-like nebula in the constellation Taurus. This prompted him to create a catalog of bright deep-sky objects that observers potentially could mistake for comets. The list became the famous Messier catalog, with the Crab Nebula in Taurus recorded as the first object, M1.

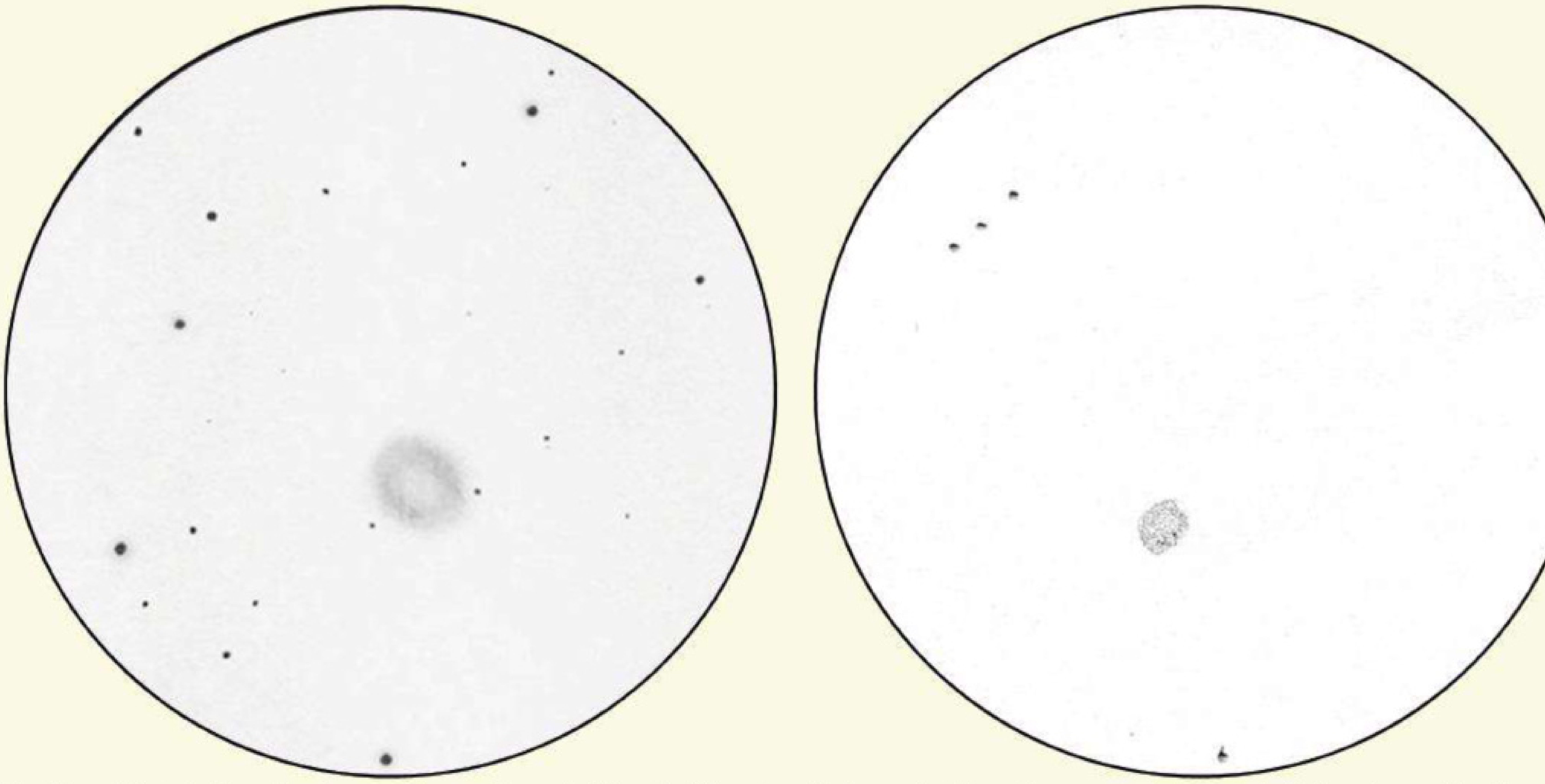
The idea of observing the entire catalog in one night originated as early as the 1960s, but the marathon didn't take off until nearly two decades later. In fact, the first written mention of the marathon occurred in the March 1980 issue of *Astronomy*. Since then, the Messier marathon has grown in popularity as a great way for amateur astronomers to test their observing skills regardless of experience level. Variations on the regular version include running the marathon with binoculars, cameras, and, yes, pencil and paper. While I already had observed the entire Messier catalog, my first marathon included the added challenge of sketching its members! Was that another gasp? Believe me, it's not as daunting as you might think.

Getting ready

Preparation is essential, so I researched websites that provided comprehensive marathon information, such as the Students for the Exploration and Development of Space

The author was eager to start her sketching marathon the night of March 13/14, 2013, as evening twilight set in.

Erika Rix *is co-author of* Astronomical Sketching: A Step-by-Step Introduction *(Springer-Verlag, 2007) and* Sketching the Moon: An Astronomical Artist's Guide *(Springer-Verlag, 2011).*



Sketching objects during a Messier marathon produces significantly different results from what the author creates during a typical observing session. For example, for a detailed sketch of the Ring Nebula (M57, left), she spent more than 45 minutes at the eyepiece, used an Oxygen-III filter, and employed a blending stump to render the nebula's soft appearance. Her sketch during the marathon (right), however, involved just a few minutes and a pencil and omitted all but four bright nearby stars for identification.

"The Messier Marathon" page (http://messier.seds.org/xtra/marathon/marathon.html). Next came choosing a date, location, and observing sequence. Mid- to late March near New Moon provides the best opportunity for locating the most Messier objects in one night. And I planned on doing two runs, one from home and the other as an event with my astronomy club. In fact, experienced observers recommend practice runs throughout the year.

As for the observing sequence, I was torn between two. One was the traditional approach of finding setting objects first, taken from Harvard Pennington's *The Year-Round Messier Marathon Field Guide* (Willmann-Bell, 1997). The other was from seasoned observer Bill Ferris' website, Cosmic Voyage (http://www.gcadventure.com/cosmicvoyage/marathon.html); his method is to locate objects as they emerge through the darkening sky while waiting for the dimmer ones to become visible. Ferris warns that the sequence during the evening hours can be risky, especially for first-time marathon runners like me.

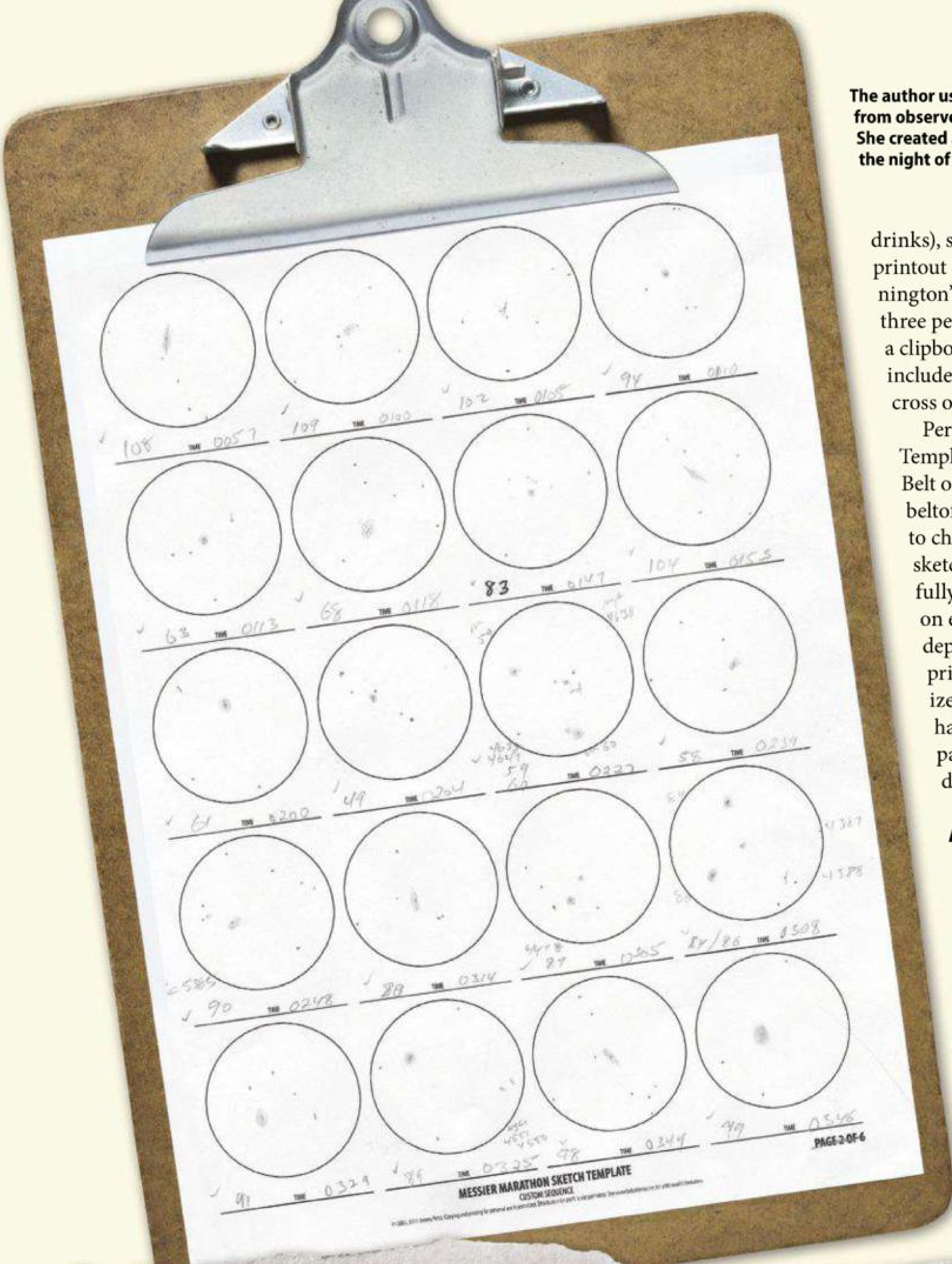
Based on these guides, I learned that time management would be important, so I'd have to budget five to 10 minutes per target and settle for basic sketches instead of detailed ones. After all, the object of the game is to bag as many Messiers as possible before sunrise. If I struggled on a target, I'd have to be willing to move on.

To aid in her all-night sketching marathon, the author kept near her telescope various supplies related to both her task and her comfort.

Keeping an eye on the extended forecast, I compiled a checklist of necessary items for the marathon. Other than my usual observing equipment — a 16-inch reflector on a non-tracking Dobsonian mount, a Telrad finder, and 13mm, 20mm, and 38mm eyepieces — I added a cooler with snacks and drinks, Tylenol, a timer, a two-way radio (destined to be a lifeline to the house for hot

Sketching Checklist

- ☐ Observing chair
- ☐ Planisphere
- ☐ Marathon sequence guides
- ☐ Red light(s)
- ☐ Sketching templates
- ☐ Clipboard
- ☐ Pencils and sharpener
- ☐ Blending stump
- ☐ Two-way radio
- ☐ Snacks and beverages
- ☐ Pain reliever



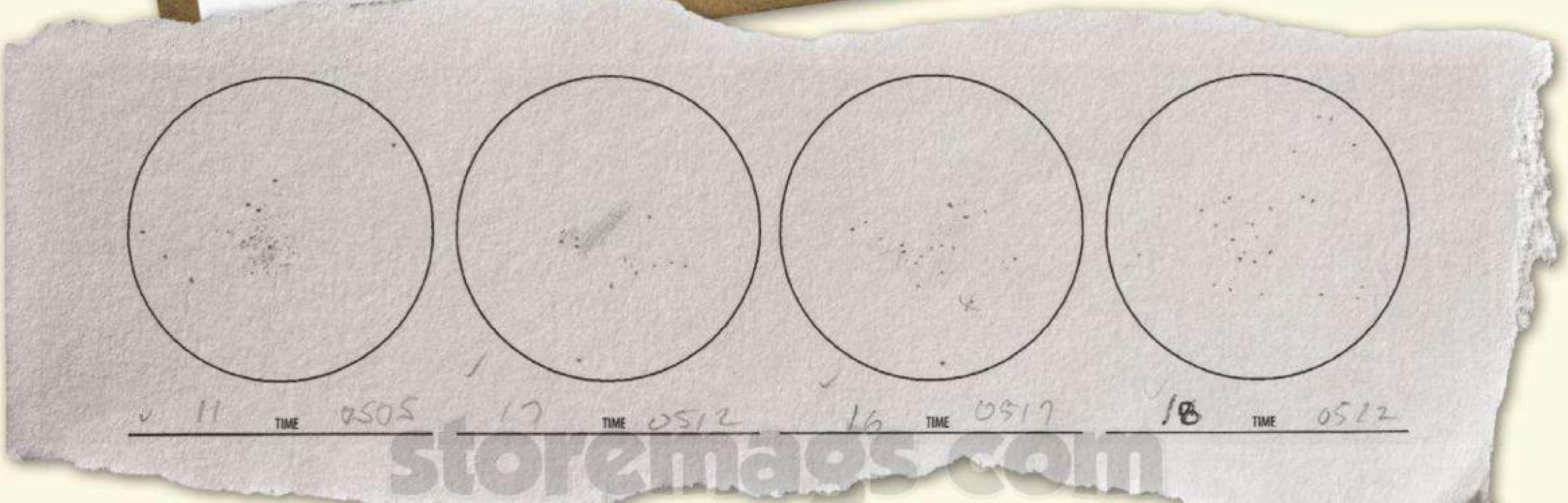
The author used Messier marathon sketching templates from observer Jeremy Perez that fit 20 objects per page. She created all of these sketches in three hours during the night of her first marathon run.

drinks), spare red lights, anti-dew equipment, a printout of Ferris' observing sequence, and Pennington's field guide. My sketch kit included three pencils plus sharpener, a blending stump, a clipboard, and sketch templates. I didn't include an eraser because it's quicker simply to cross out a misplaced star.

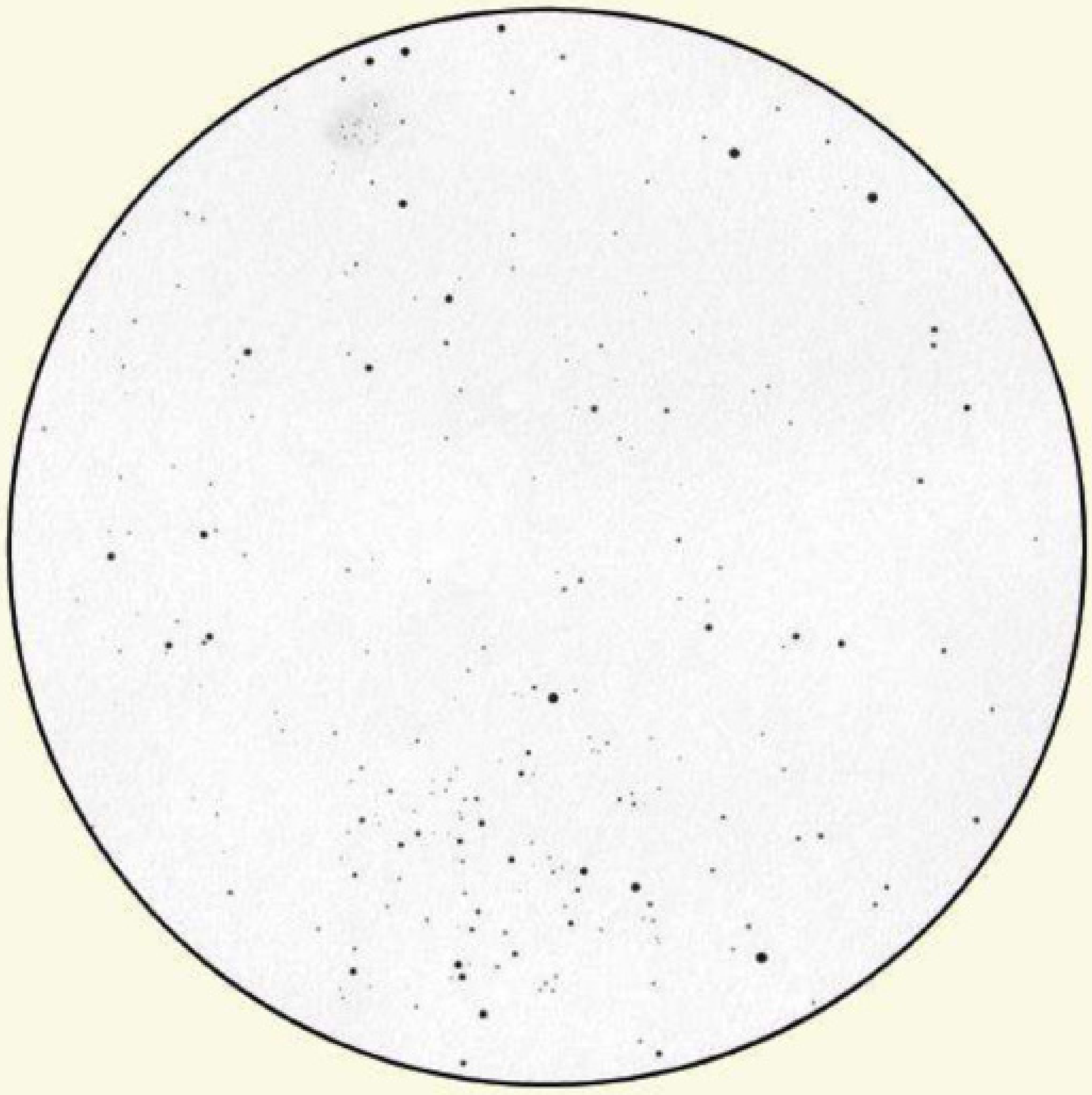
Perez designed "Messier Marathon Sketch Templates" to print from his website, The Belt of Venus (http://www.perezmedia.net/beltofvenus/marathon.html; make sure to check out his 2009 Messier report and sketches while you're there!). These carefully designed forms fit 20 Messier objects on each page, with different versions depending on your observing sequence. I printed the blank set so I could customize the list order. In hindsight, I should have used water-resistant Rite in the Rain paper, which holds its integrity during damp observing conditions.

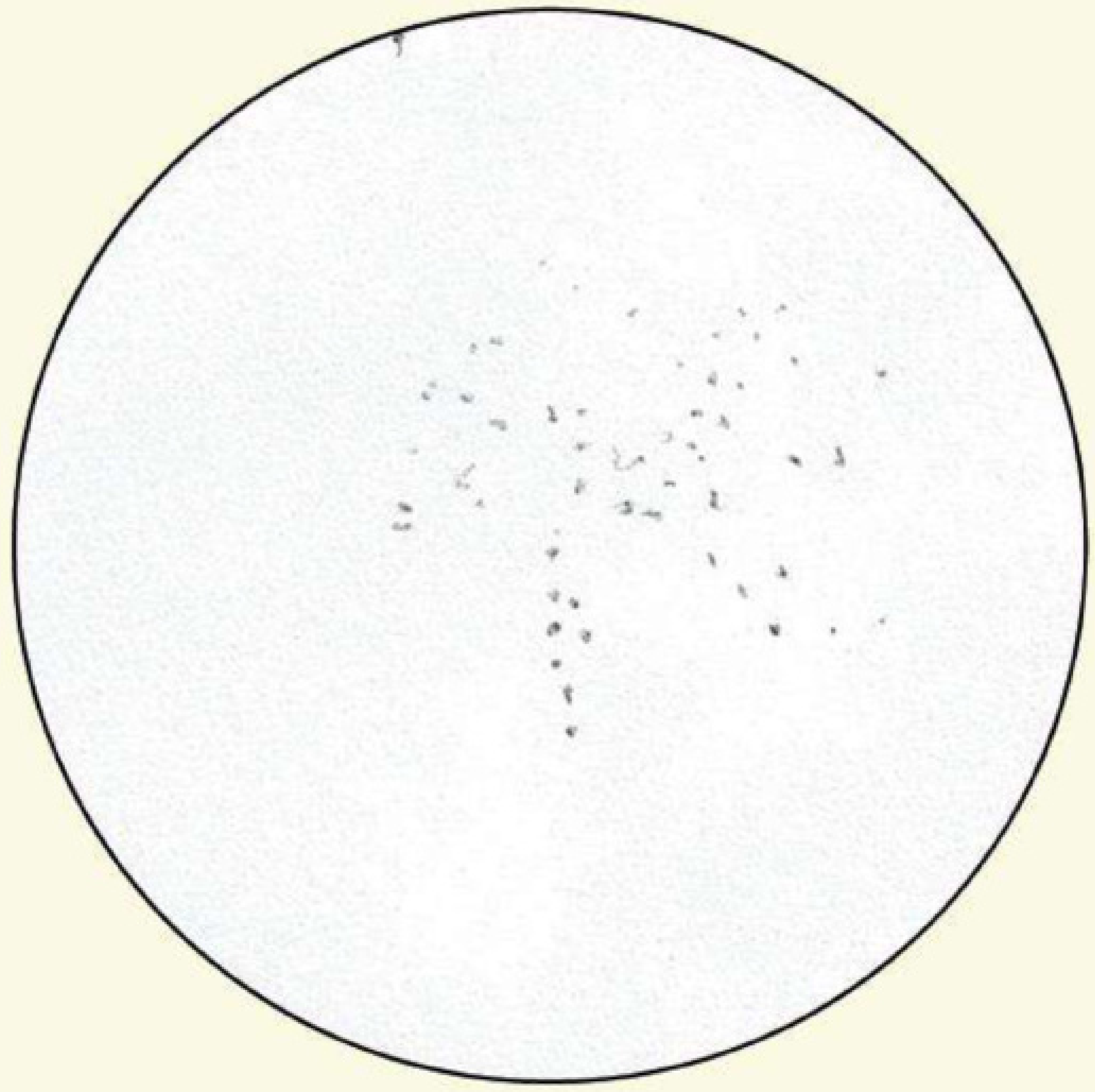
All-night sketching

My first marathon was March 13/14, 2013, from a field near my home with low northwest and southeast horizons. I spent the afternoon hours setting up and organizing my gear for easy access during the night. Just after twilight, I set the timer for 10 minutes and glanced at the sky. The western horizon was still too light for spiral galaxy M74 in Pisces, Pennington's recommended starting point, so I decided to use Ferris' sequence. The Orion Nebula (M42) and nearby M43 as well as the Pleiades (M45)



When working on complex targets like M11, M17, M16, and M18, aim for sketching their basic shapes and identifiable star patterns.





Although not her typical rendition of M38 (shown at left, magnification of 150x), which took the author more than an hour to render at the eyepiece, the sketch of the open cluster during her marathon night (right, magnification of 91x) still includes the basic "X" shape, and it only took a minute or two to capture.

in Taurus were the first sketches of the night, including only a few prominent field stars and rough renditions of the objects. I checked targets off the list as I recorded their Messier numbers and times on the templates.

Next were open clusters M103 and M52 in Cassiopeia. It's time-consuming to plot the numerous stars in open clusters, so I needed a faster approach. I decided to sketch only their identifiable star patterns and basic shapes. To illustrate M103, I concentrated on two chains of stars that form a "V" opening to the southeast. The brightest four stars of the prominent chain run southeast to northwest. I also included the trio of stars that form a small triangle just northeast of the cluster to help with identification.

By this point, M74 was slipping lower in the sky. Skipping forward in the list, I chose that galaxy as my next target, with no success other than running over budget on time. I knew I should have completed several more sketches by that stage, and to make matters worse, I felt pressured by the timer. It was time to reassess my plan.

The first thing to go was the timer. I then switched to the traditional order found in Pennington's field guide and began working on lower targets at the beginning of the sequence. Hanging a red light from my focuser and removing the one from my clipboard helped with organization. The new light placement could illuminate both the field guide and the clipboard, which I cradled with my left arm. I also tossed the blending stump aside because it was faster to sketch nebulosity directly with a pencil.

But the best change was to take pressure off myself. After all, it was my first marathon — and a sketching one at that! I had already accepted that my sketches would be identifiable at best. It was time to just give it my best effort and enjoy the experience. From that moment on, everything ran like clockwork — that is, until I came to Virgo.

Navigating Virgo during the marathon wasn't that difficult, but the huge number of galaxies in a relatively small region of sky did slow things down. I returned to "home base" (a term Pennington uses when referring to a starting point) a few times and even referred to a star map app on my smartphone. Being able to include multiple objects in a single sketch made up for lost time.

Some observers are able to grab a nap at this point, but I pressed forward. Somehow, I managed two to three minutes per object in Ophiuchus despite the fatigue and clumsiness that set in. My legs were getting shaky, my neck hurt, and a headache was forming by the time I reached Scutum at 5 A.M., so the Tylenol and my observing chair both came in handy.

I could hear the morning bird songs by the time I hit Sagittarius. The end of the marathon was near. I had an abundance of sketches left to do, but determination set in. I managed to capture globular cluster M2 in Aquarius but missed out on its constellation companions, M72 and M73, as well as M30 in Capricornus.

Looking back and ahead

With the light of day, my first Messier (and sketching!) marathon was over. Much to my dismay when reviewing the sketches, I found that I had missed drawing the Andromeda Galaxy (M31) and its companion, M32, even though I distinctly remembered observing them. Disappointing as that was, I was thrilled with the final results of 105 observed and 103 sketched out of the 109 total objects.

The first run was under my belt. My astronomy club's event was just three nights later, though the forecast was bleak. This time, I filled in the Messier numbers on the sketch templates ahead of time to prevent omissions. I caught M74 and grabbed sketches of M31 and M32, steadily making my way through the list with confidence.

Unfortunately, overcast skies ended the marathon shortly after midnight, but that didn't stop the group from enjoying each other's company with hot drinks and homemade cookies. When I counted the objects I had sketched by 12:30 A.M., the total was 42, and I had been making better time than on the first run!

If you're ready to try a Messier sketching marathon, remember the essentials for a successful run — preparation, planning, and time management. But above all, relax and enjoy the experience!

Explore the Virgo cluster through binoculars

Set a goal this spring: 14 galaxies in 2014. **by Phil Harrington**

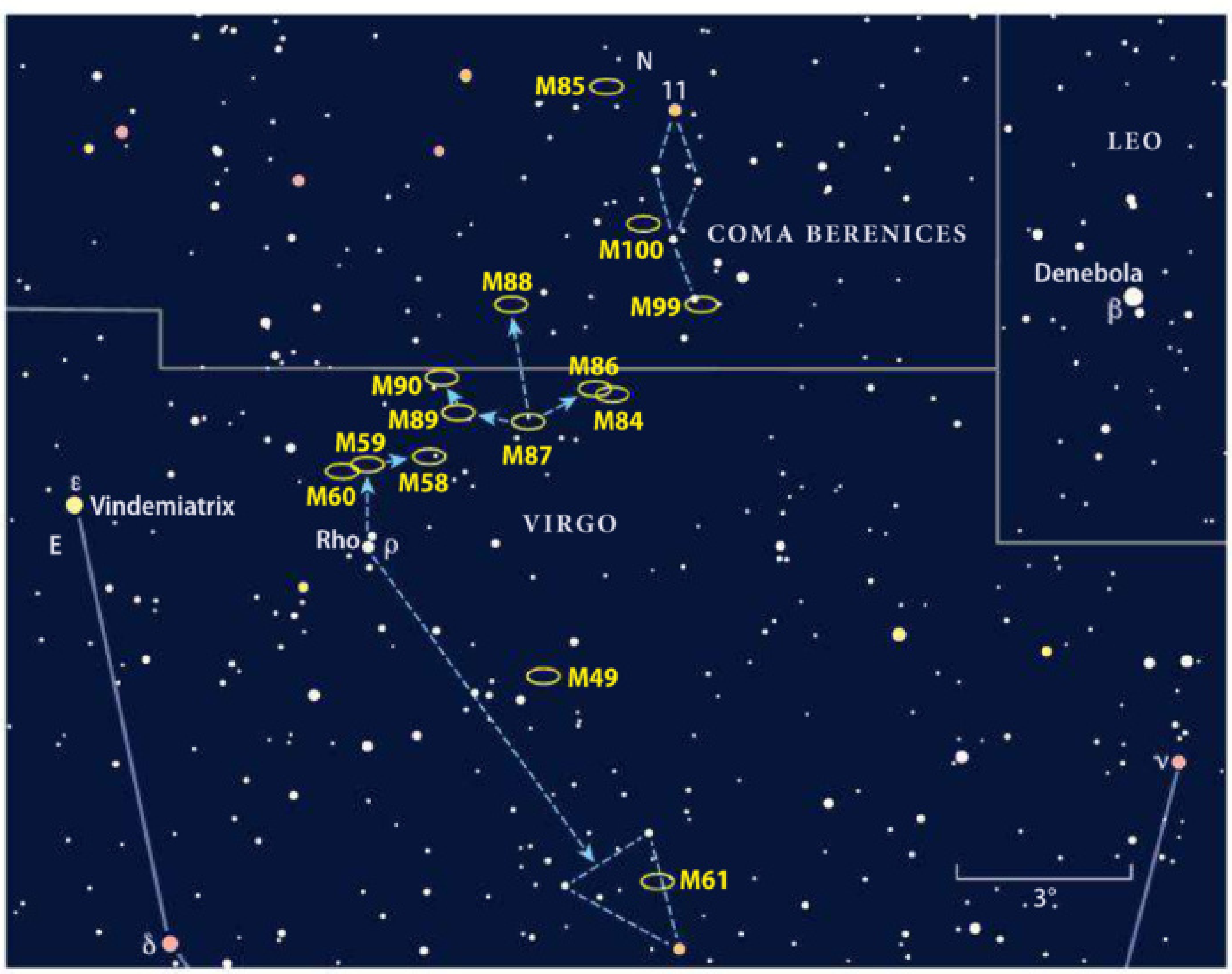
Wading through the Coma-Virgo Galaxy Cluster, known to early-20th-century observers as the "Realm of the Nebulae," is a daunting task for observers. Here, wedged between Denebola (Beta [β] Leonis) and Vindemiatrix (Epsilon [ε] Virginis), lie more than a dozen galaxies cataloged by Charles Messier and scores of others listed in the *New General Catalogue*.

Many amateurs think the Realm is only accessible through telescopes. Not so, as we are about to see. Nearly all of its Messier objects are within reach of binoculars.

But before you try something as challenging as the Coma-Virgo cluster, you should attach your binoculars to a tripod or other support. This goes for binoculars with image stabilization as well. While their technology does help calm jitters, a tripod makes it much easier to refer back and forth to a chart without having to re-aim the binoculars each time.

Let's begin with one of the brightest of the bunch, **M87**, at the heart of the Realm. It lies almost exactly halfway between Denebola and Vindemiatrix. From Vindemiatrix, find Rho (ρ) Virginis, a binocular double star, and then steer an equal distance northwest.

Keep an eye out for M87's central core, which will look like a faint fuzzy "star" surrounded by a circular mist. In reality, this is a monstrous elliptical galaxy perhaps 10 times more massive than our Milky Way. The luminous jet of material seen bursting from its core (in photographs) results from a supermassive black hole buried within.



Use the order in the text, this chart, and your binoculars to navigate through the brightest members of the Coma-Virgo cluster. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

OK, don't move a muscle. Keep M87 centered, and let your gaze drift toward the west-northwest (to the upper right). Can you see two smaller smudges that nearly touch each other? The western (rightmost) member of the pair is **M84** while **M86** is the eastern system.

Each of these elliptical galaxies shows a round or slightly oval disk through binoculars with magnifications of 12x or more. You also might detect tiny stellar cores. With just a casual glance, both of these 9th-magnitude galaxies look identical. But a closer look shows M84 to be a little smaller and a bit brighter than its neighbor.

Now — again without shifting your aim — look to the east (left) of M87 for two more faint disks. **M89** and **M90** form a challenging galactic duo, with M90 hugging the border between the constellations Virgo and Coma Berenices. M89, a 10th-magnitude elliptical, can prove difficult to detect through 50mm binoculars with magnifications under 10x, especially from a less than perfect observing site.

M90 is just northeast (upper left) of M89, beyond an asterism of five faint stars in a W pattern that resembles the main part of the constellation Cassiopeia. With a bit of study, especially through 70mm and larger binoculars, this spiral shows a faint stellar center girded by the oval glow of tightly wound arms.

Our next target, **M88**, lies 2° due north of (above) M87. M88 is a spiral galaxy characterized by moderately loose arms. Binoculars reveal a medium-bright core engulfed by the spiral arms' faint oval glow.

We can use a kite-shaped asterism of faint stars northwest (upper right) of M88 and due east (left) of Denebola to find three

Phil Harrington *is an* Astronomy *contributing editor and author of* Cosmic Challenge *(Cambridge University Press, 2010).*

The two brightest galaxies in this image are M86 (left) and M84. The bluish star shines at 10th magnitude. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

M100 shines brightly for a galaxy at magnitude 9.4. But it appears tiny and faint through binoculars, so be patient when you're searching for it. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

more Messier galaxies. **M99** lies just south of the kite's tail. It glows dimly at 10th magnitude and is a tough test through binoculars. Can you spot it?

If you can, then try your luck with an even more challenging target. **M100** is rated half a magnitude brighter than M99, but that is misleading. Due to M100's larger apparent diameter, its surface brightness is lower than M99's. Both targets may require 70mm or larger binoculars to confirm.

If the last pair proved too tough, take heart. The third galaxy here, **M85**, is a little less demanding. You'll find it 1.2° east-northeast (left) of the kite's top star. Although only faintly visible through 10x50 binoculars on dark nights, it's relatively easy to catch using 16x70s even from light-polluted suburban skies.

Now, return to Rho Virginis and look about 1.5° north (above) for **M58**, **M59**, and **M60**. Of these, the easternmost (leftmost), M60, is the easiest to spot. Its round glow may remind you of a faint globular cluster. M59, which lies west (right) of M60, is tougher and will probably require averted vision. M58 is just as demanding and takes a good eye and patience. Look for its soft glow west (right) of the other two galaxies, but don't confuse it with M89 to its northwest (upper right). M58 and M59 are faint but should be discernible with patience.

We have two more Messier galaxies to go, both quite a bit southwest (lower right) of Rho. Messier saw **M49** "only with difficulty" in February 1771. You may find that it leaves a brighter impression because it stands out fairly well through 10x50 binoculars. Of course, it's quite a different matter to discover something for the first time than it is to see something you know exists. You'll find it 3.7° southwest of Rho. M49's 8th-magnitude oval disk makes it the second-brightest galaxy in the Realm.

Finally, we have another test — **M61**, which lies in a triangle of faint stars 4° south-southwest (lower right) of M49. Photographs reveal this 10th-magnitude galaxy to be a face-on spiral. Like most galaxies of that type, M61 has a notoriously low surface brightness. That makes it tough to see through any binoculars with apertures smaller than 50 millimeters.

Hopefully, you've enjoyed the challenge of touring the Realm of Galaxies with binoculars. It's fun to push our limits and prove, even for galaxy-hopping, that two eyes are better than one.

DISCOVER MORE SPRING BINOCULAR TARGETS AT **www.Astronomy.com/toc.**

Image **the solar system** with Celestron's Skyris

Good sensitivity, high-quality construction, and a lightweight package make these CCD cameras must-have planetary imagers.

by Damian Peach

During the past year or so, amateur astronomers have seen quite an upturn in the number of new cameras geared toward the solar, lunar, and planetary imager hitting the marketplace. Never before have we had so many terrific choices in equipment — and we can own many of them for a surprisingly modest price.

Celestron recently entered the marketplace with its Skyris series. The design and engineering for these cameras came from The Imaging Source in Germany in collaboration with Celestron's engineers.

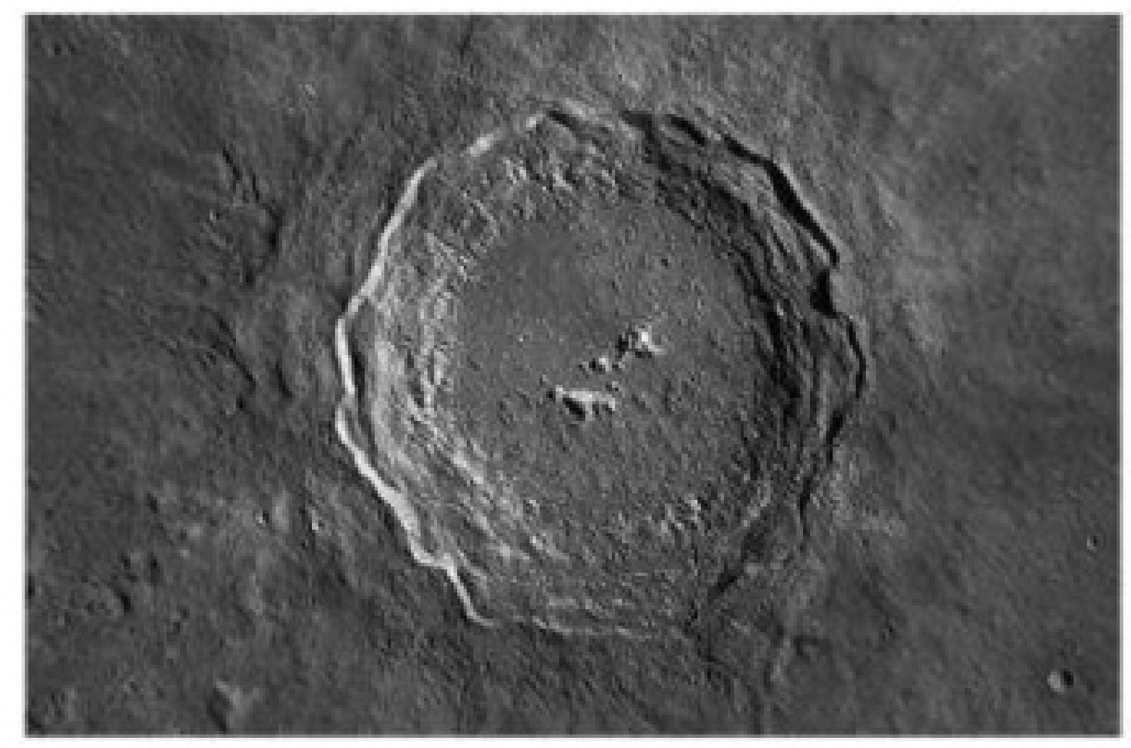
Unlike the company's several basic models, such as the NexImage, the Skyris cameras target more serious solar system imagers. For this review, I tested two units under the night sky — the Skyris 618C and the Skyris 445M.

Damian Peach *is one of the world's top astroimagers. He usually sets up and shoots from Hampshire, England.*

Facts, figures, and use

The 618C contains a 640x480 array with 5.6-micron pixels based on the Sony EXview HAD ICX618AQA color CCD sensor. It operates via a high-speed USB 3.0 connection and can deliver frame rates up to 120 frames per second (fps) at full frame in 12-bit color mode. The camera comes with *iCap* capture software and a copy of *RegiStax 6* for processing the captured images. The box also contains a 1¼" nosepiece for easy connection to any 1¼" focuser and an instruction manual.

The 445M camera is quite a different beast altogether. It has a larger 1280x960 array with 3.75-micron pixels based on the Sony EXview HAD ICX445ALA monochrome CCD sensor. This camera also operates via USB 3.0 but offers download speeds of 30 fps at full frame in 12-bit monochrome mode. It comes with the same accessories as the 618C, and, indeed, both cameras look identical on the outside. Both are also well made, being of all metal construction and anodized in black.



The author captured the lunar crater Copernicus using the Skyris 445M camera. Its large chip makes it ideally suited for lunar and solar imaging where larger fields of view are desirable. DAMIAN PEACH

Installing both cameras was straightforward, and the instructions in the small manual included are clear and concise. I quickly had both cameras up and running with the supplied *iCap* software. I ran both on a midrange laptop with an Intel core i5 processor. The system had no trouble running either camera.

With some brief daytime testing completed, I waited for a clear night to try the cameras under the night sky. The Moon and Jupiter were both available throughout the review period, so I seized the opportunity to point both cameras at these targets.

Under the night sky

Each of these objects is challenging in different ways, and I had high hopes for the performance of the Skyris cameras given the technical specifications.

Both cameras require different setups to achieve the correct image scale because of their noticeably different pixel size. (The 445M has pixels around 35 percent smaller

Celestron and The Imaging Source designed the Skyris 618C and Skyris 445M to use the same body, although each contains a different chip. (Camera is actual size.) CELESTRON

than the 618C.) The 618C is an especially convenient system for planetary imaging because it gives a true-color live view, meaning you don't need filters. I was most impressed with this camera compared to competing color cameras I've used.

The USB 3.0 connection in both cameras allows high frame rates, so you can collect a large number of frames in a short time — vital for a fast-rotating object like Jupiter. In fact, you can get a decent result in as little as 60 seconds. With longer exposure times, you'll produce smooth results. This is important for color cameras like the 618C because they tend to be noisier than their monochrome counterparts.

As stated above, the 445M's smaller pixels require a different setup. This can prove awkward on long-focal-length telescopes such as Schmidt-Cassegrains using the typically available tools for image amplification such as 2x or 3x Barlow lenses. (The latter accessory, for example, boosts the apparent focal length all the way up to 6,000 millimeters.)

The 445M's larger array and small pixel size made it a really wonderful camera for lunar and solar imaging. Where before, using other smaller-chipped cameras, I needed to do mosaics to cover large craters, now I could shoot them in one take using the 445M, which makes imaging the Moon a lot more enjoyable.

I've spent many years making lunar mosaics, so a camera like this is a pleasure to use. It performed well on both the Moon and Jupiter, although if you want to take color images with it, you'll need filters.

Overall, both cameras delivered high-quality results. The 618C is a convenient planetary camera, and the 445M is well-adapted for wider targets like Moon craters (though it also does a great job with Jupiter). Both cameras are sensitive, although the 445M is a little more so and less noisy.

The only slight negative is that the *iCap* software that comes with the cameras is not easy to come to grips with. It was not always clear where certain functions were. Compared to other packages available, it isn't as slick in function or layout. On the other hand, it's great to see Celestron including *RegiStax 6* image-processing software with the camera — an especially nice touch for those just starting out.

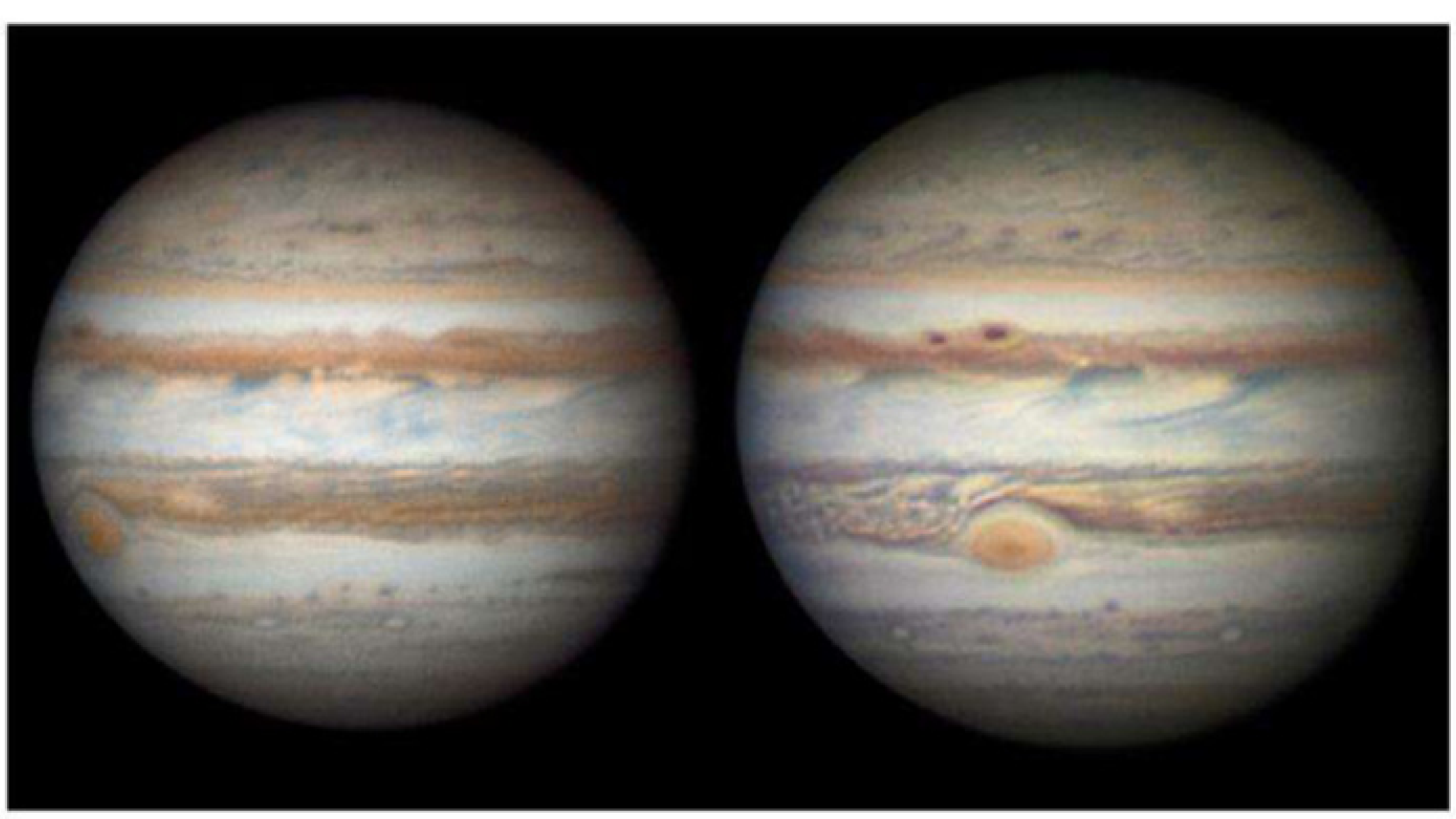
Pick one

Both of these cameras really impressed me. They are of high quality and perform well in the field. I especially liked the 618C. Finally we have a high-speed color CCD camera on the market capable of delivering nice results, all through a simple USB 3.0 interface. I can see this camera becoming a popular choice among planetary imagers both old and new.

The 445M is also excellent. It is more flexible in its uses, but being a monochrome model, it's more suited to the experienced imager. It certainly will serve amateur astronomers well as their primary camera, and the larger array size makes it especially nice for lunar or solar work.

Based on my testing of the Skyris 618C and 445M, these cameras would make excellent choices for either a novice or experienced imager, and the 618C is probably one of the best color cameras currently available. Both are worth checking out.

Celestron includes everything you need in the box with the Skyris 618C and 445M cameras. CELESTRON


The author captured Jupiter with the Skyris 445M (left) and 618C. Both cameras deliver impressive results, although of course the 445M requires filters to produce color images such as this. DAMIAN PEACH

PRODUCT INFORMATION

Celestron Skyris CCD cameras

Model	618C	445M
Resolution:	640x480	1280x960
Pixel size:	5.6 microns	3.75 microns

Mounting: 1¼" barrel and C-thread
Exposure range: 0.0001 to 30 seconds
Power: Powered by USB
Weight: 3.6 ounces (102 grams)
Included: 1¼" nosepiece, 10-foot USB 3.0 cable, Celestron *iCap* capture software, *RegiStax 6* software

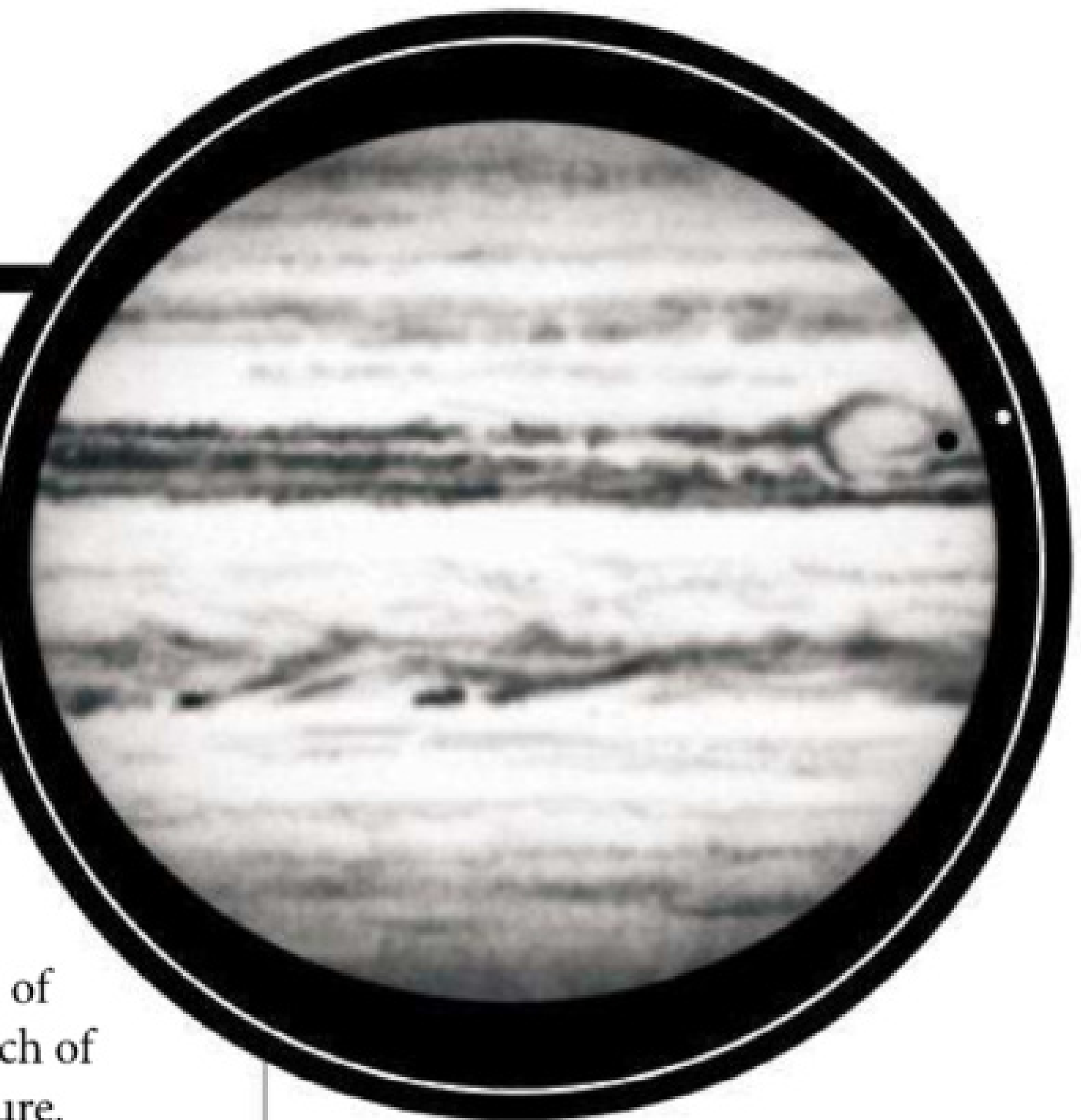
Price:	$499.95	$649.95

Contact: Celestron
2835 Columbia Street
Torrance, CA 90503
[t] 310.328.9560
[w] www.celestron.com

ASTRO**SKETCHING**

BY ERIKA RIX

Mastering Jupiter's atmosphere



On November 5, 2011, between 9:39 and 9:52 P.M. EDT, the sketcher recorded Jupiter, Io, and the moon's shadow, which was transiting (crossing) the giant planet's cloud tops. He used 4H and HB pencils as he viewed through a 6-inch refractor at f/7.46 with a 5mm eyepiece (224x) and a Sirius Optics Jupiter beta test filter. South is up, and the preceding limb is to the left.

If you've ever sketched a solar prominence or tackled the lunar terminator, you've gotten a taste of drawing fast-moving scenes with little time to spare. Jupiter falls into this category.

With a rotation rate of nine hours and 55 minutes, the giant planet's features appear quickly and disappear just as fast. This month, Jupiter makes a great target because it reached opposition (when it lay across the sky from the Sun as seen from Earth) January 5. That means this month, it rises before sunset and is high in the sky during the more convenient evening hours.

You'll have no trouble finding Jupiter after evening twilight fades, shining brighter than anything else in the southern sky. Currently, it lies in the constellation Gemini the Twins. For best results, sketch it when it lies due south because that's when the gas giant will be at its highest and you'll be looking through the least amount of our atmosphere. Air turbulence washes out detail, so strive for a night when you get an undistorted view using a magnification of 25x to 35x for each inch of your telescope's aperture.

A fascinating feature to observe in Jupiter is its weather patterns. Its atmosphere is mainly hydrogen, helium, and other compounds that, when condensed, form bands across the planet's disk. Color filters can enhance these features, so make sure to try a few during your observation.

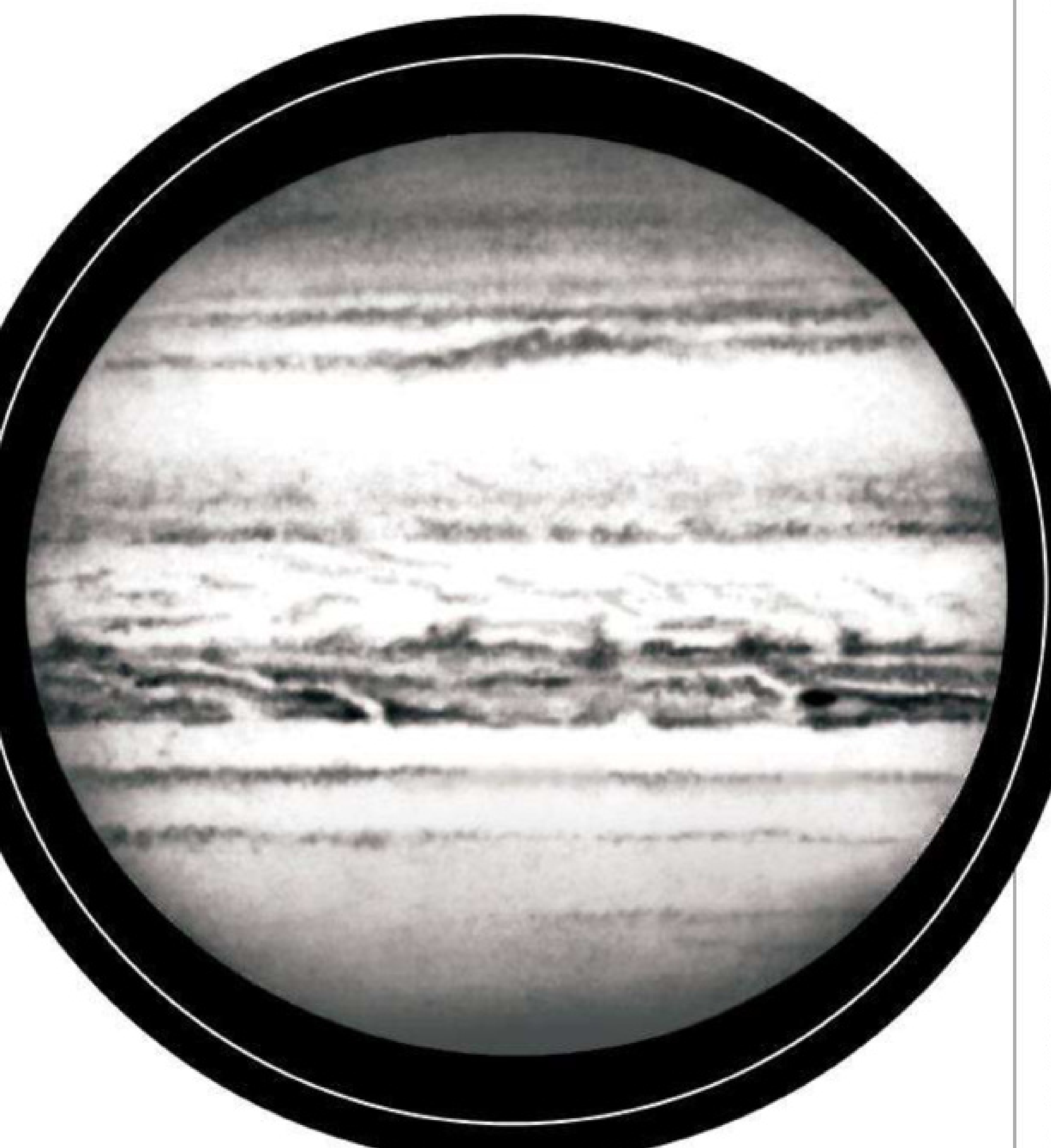
Through the smallest telescopes, you'll see the Galilean moons — Io, Europa, Ganymede, and Callisto — easily, plus you'll pick up hints of Jupiter's equatorial belts. Although you can see the giant storm known as the Great Red Spot through a 3-inch telescope, colors and features within the belts become more defined using larger scopes. Something else a telescope will reveal is that the planet's rapid rotation pushes material toward the equator, creating an elliptical shape. A Jupiter-observing template illustrating this can be found on the Association of Lunar and Planetary Observers website at http://alpo-astronomy.org.

As you observe, record the time and draw the boundaries of the major belts you see. Next, add prominent features you can use as reference points, then fill in the remainder of the sketch. Start with the preceding limb (the edge of the planet where features are disappearing) to catch details before they rotate out of view. Be prepared to render subtle tones when they emerge during moments of the sharpest seeing.

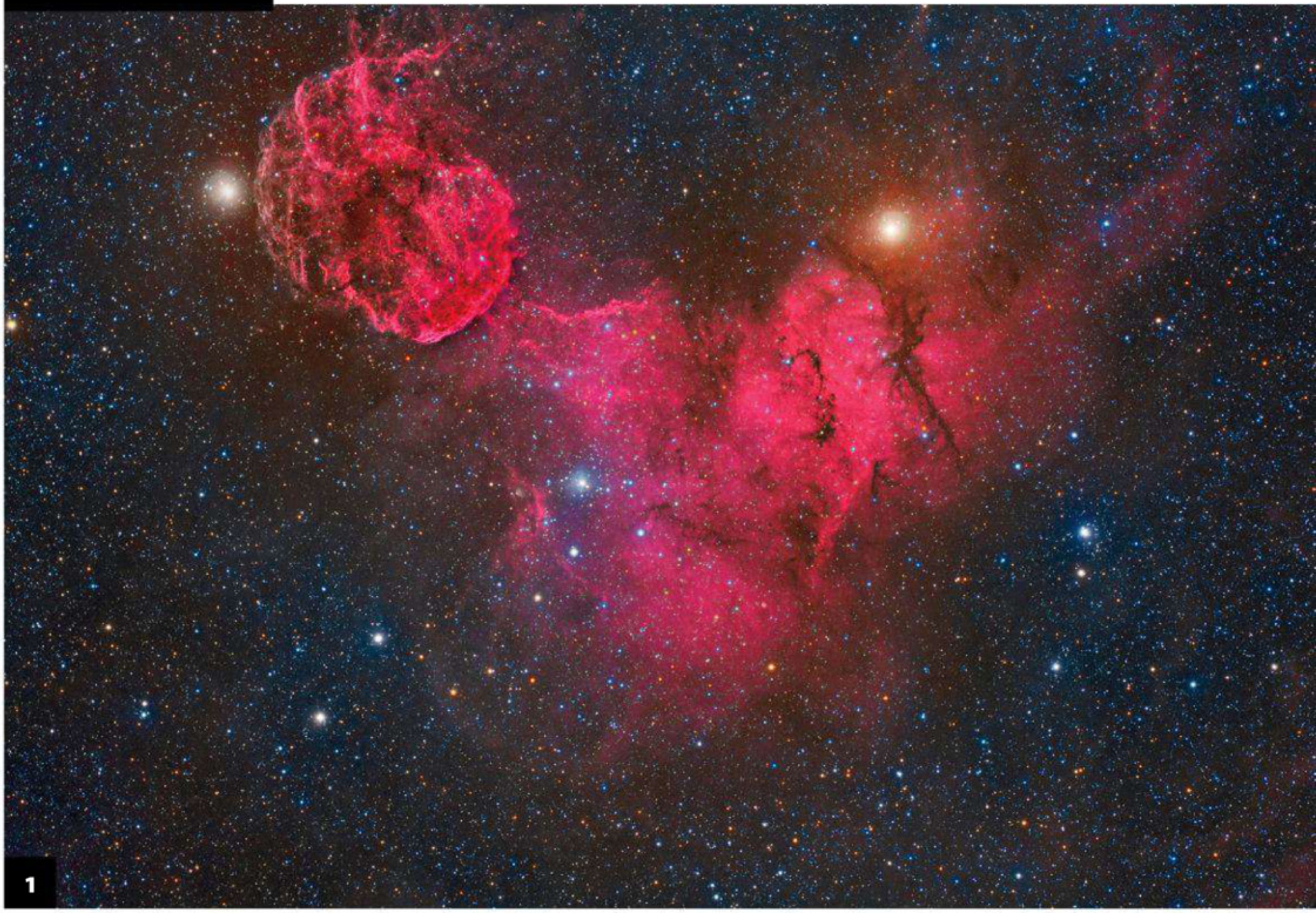
Try varying your sketches. You're not limited to drawing the entire disk. For example, you can create strip sketches by focusing solely on the equatorial belts or by mapping Jupiter during a period of several hours. Planetary observer Paul Abel recorded more than half the planet over six hours by creating a strip map, which you can see on the Astronomy Sketch of the Day website at www.asod.info/?p=9636.

Your sketch kit should include assorted graphite pencils graded for hardness and blackness. For example, a 4H pencil has hard lead that produces faint strokes, whereas a 4B pencil will let you create dark black markings. An HB falls in the middle of the pencil range. Using an eraser shield (a metal or plastic plate with different sizes and shapes of openings) gives you more control as you draw belts or satellite transits.

Remember, sketching skills improve with each observation, so keep at it. You'll soon become a master at sketching the jovian atmosphere.

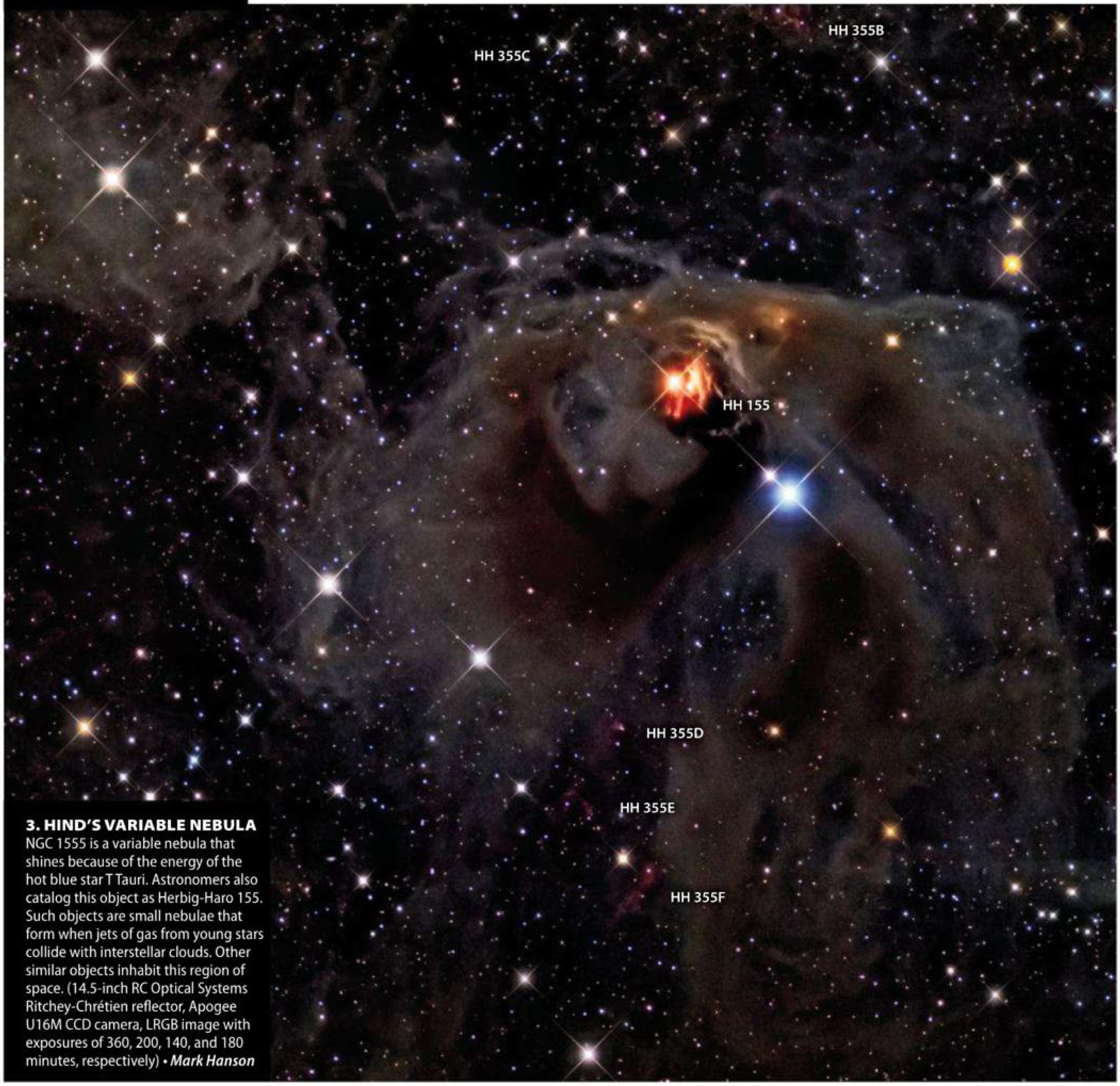


The observer made this sketch using 4H and HB pencils October 13, 2010, between 10:30 and 10:53 P.M. EDT. He used a 6-inch f/8.3 reflector with a 10mm eyepiece and a 2x Barlow lens, which provided a magnification of 249x. South is up, and the preceding limb (the edge of the planet where features are disappearing) is to the left. BOTH SKETCHES BY SOL ROBBINS



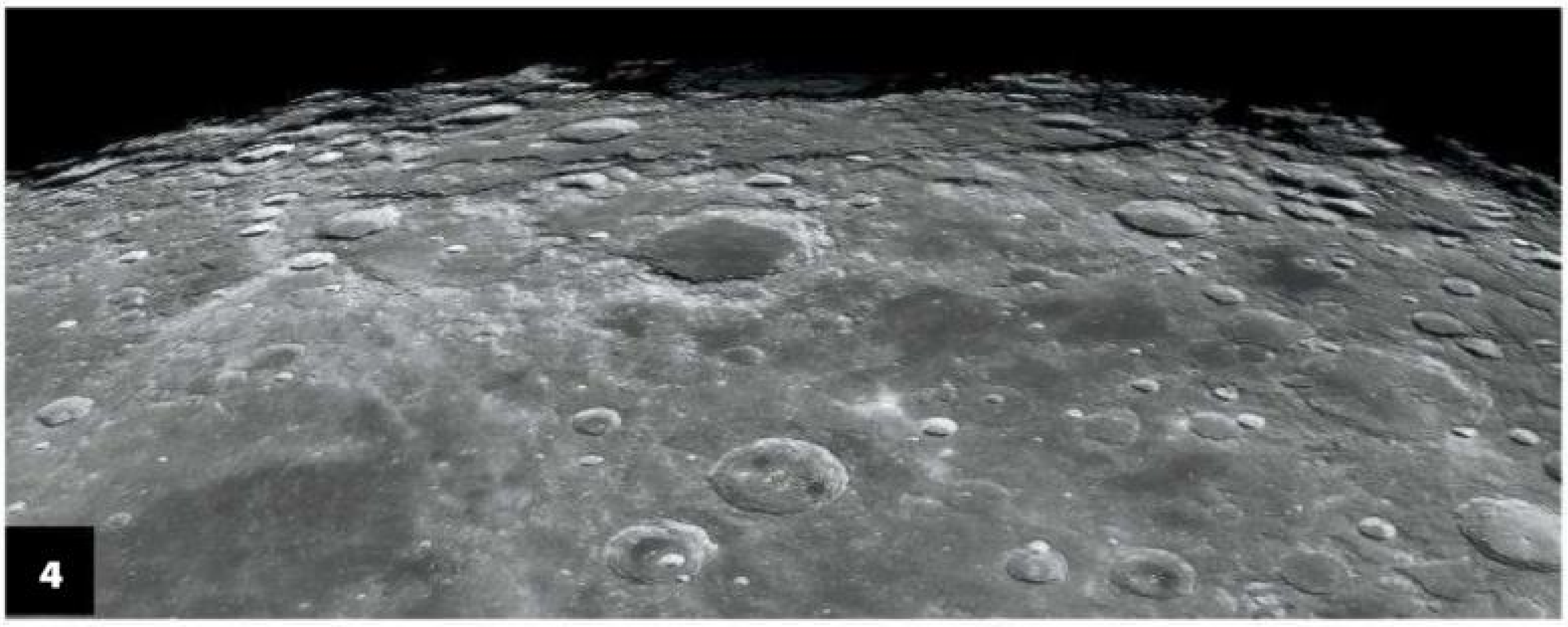
1. THE JELLYFISH NEBULA
Supernova remnant IC 443 (upper left) looks to some like a celestial jellyfish. It lies in Gemini with Sh 2–249, the nebula to the Jellyfish's lower right. (4-inch Takahashi FSQ-106N refractor, SBIG STL-11000 CCD camera, HαRGB image with exposures of 510, 70, 70, and 70 minutes, respectively, taken remotely from the Rancho Hidalgo Astronomy and Equestrian Village near Animas, New Mexico) • ***Eric and Josephine Africa***

2. OUR GALAXY
The Milky Way shines brightly above the Alqueva Dark Sky Reserve in Portugal, the first site in the world to receive the "Starlight Tourism Destination" certification. The imager captured Vega (Alpha [α] Lyrae, upper left), the Andromeda Galaxy (M31, left), and Antares (Alpha Scorpii, right) in one shot. (Canon 60Da DSLR, 24mm lens at f/2, ISO 2000, 20-second exposure) • ***Miguel Claro***



3. HIND'S VARIABLE NEBULA
NGC 1555 is a variable nebula that shines because of the energy of the hot blue star T Tauri. Astronomers also catalog this object as Herbig-Haro 155. Such objects are small nebulae that form when jets of gas from young stars collide with interstellar clouds. Other similar objects inhabit this region of space. (14.5-inch RC Optical Systems Ritchey-Chrétien reflector, Apogee U16M CCD camera, LRGB image with exposures of 360, 200, 140, and 180 minutes, respectively) • ***Mark Hanson***

4. TOUGH TO SEE SEA
Mare Humboldtianum (Humboldt's Sea, top center) is difficult to image because it lies at the Moon's northeastern edge. Endymion Crater lies below it and features a dark floor. (11-inch Celestron CPC-1100 EdgeHD Schmidt-Cassegrain telescope at f/10, ZW Optical ASI120MM CCD camera, mosaic of two images of 1,000 frames each, taken October 19, 2013, from Memphis, Tennessee) • ***Ross Sackett***

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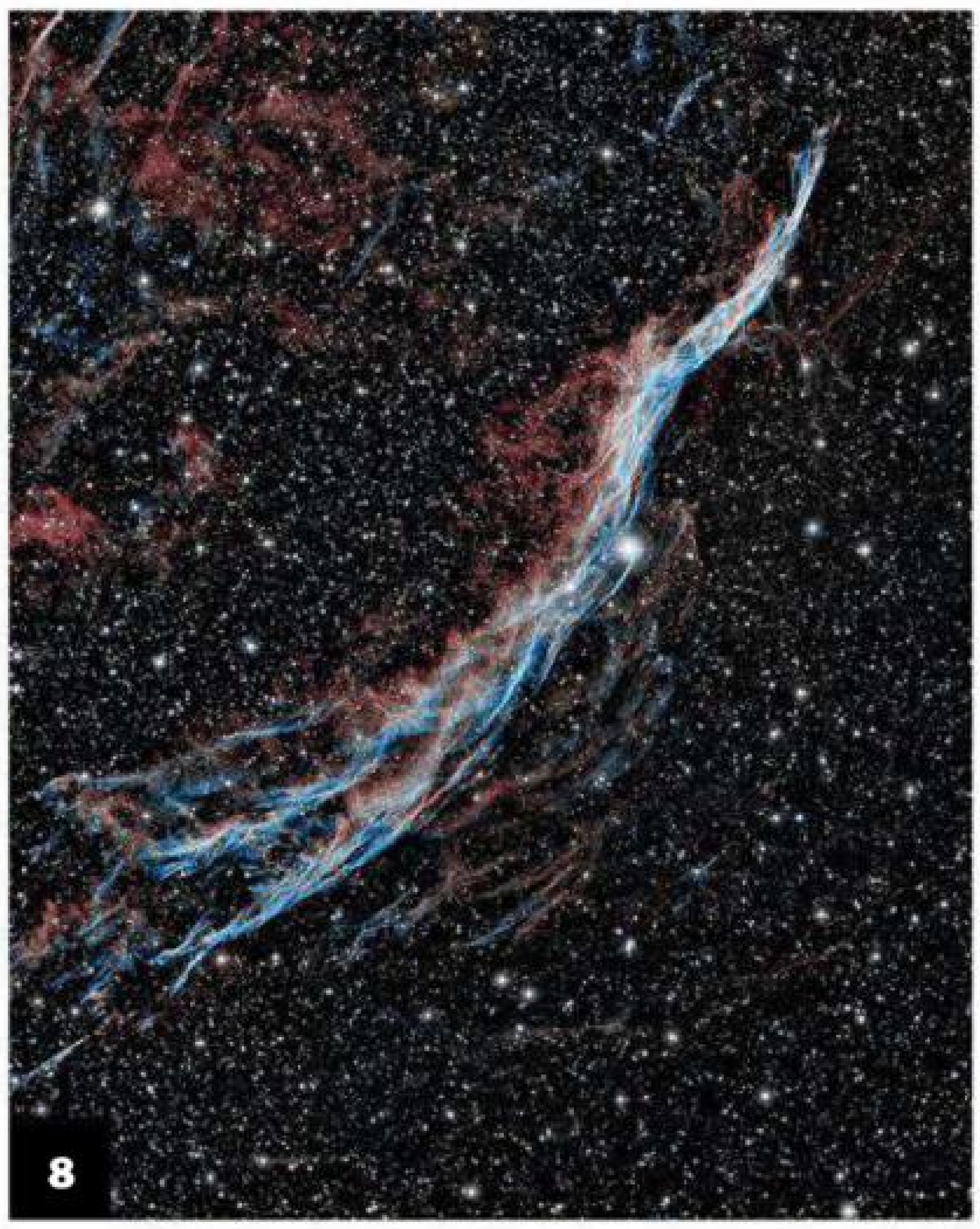
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5. THE SQUID
The blue bipolar nebula Ou4 floats in front of reddish emission nebula Sharpless 2–129. Both objects lie in the constellation Cepheus. (6.2-inch Telescope Engineering Company TEC-160 refractor at f/7, SBIG ST-11000M CCD camera, Hα/OIII/LRGB image with exposures of 330, 960, 420, 225, 225, and 225 minutes, respectively) • ***Lee Buck***

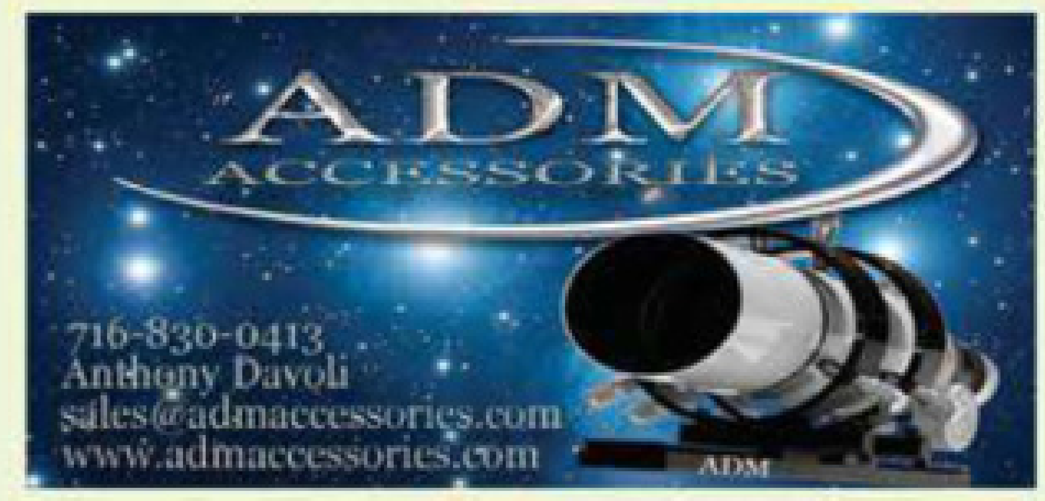
6. GALACTIC DUO
M87 is a giant elliptical galaxy in Virgo. A mysterious energetic jet of material (right side of galaxy) emanates from its center. (24-inch RC Optical Systems Ritchey-Chrétien reflector, SBIG STL-11000 CCD camera, LRGB image with exposures of 66, 20, 20, and 20 minutes, respectively) • ***Adam Block/Mount Lemmon SkyCenter/University of Arizona***

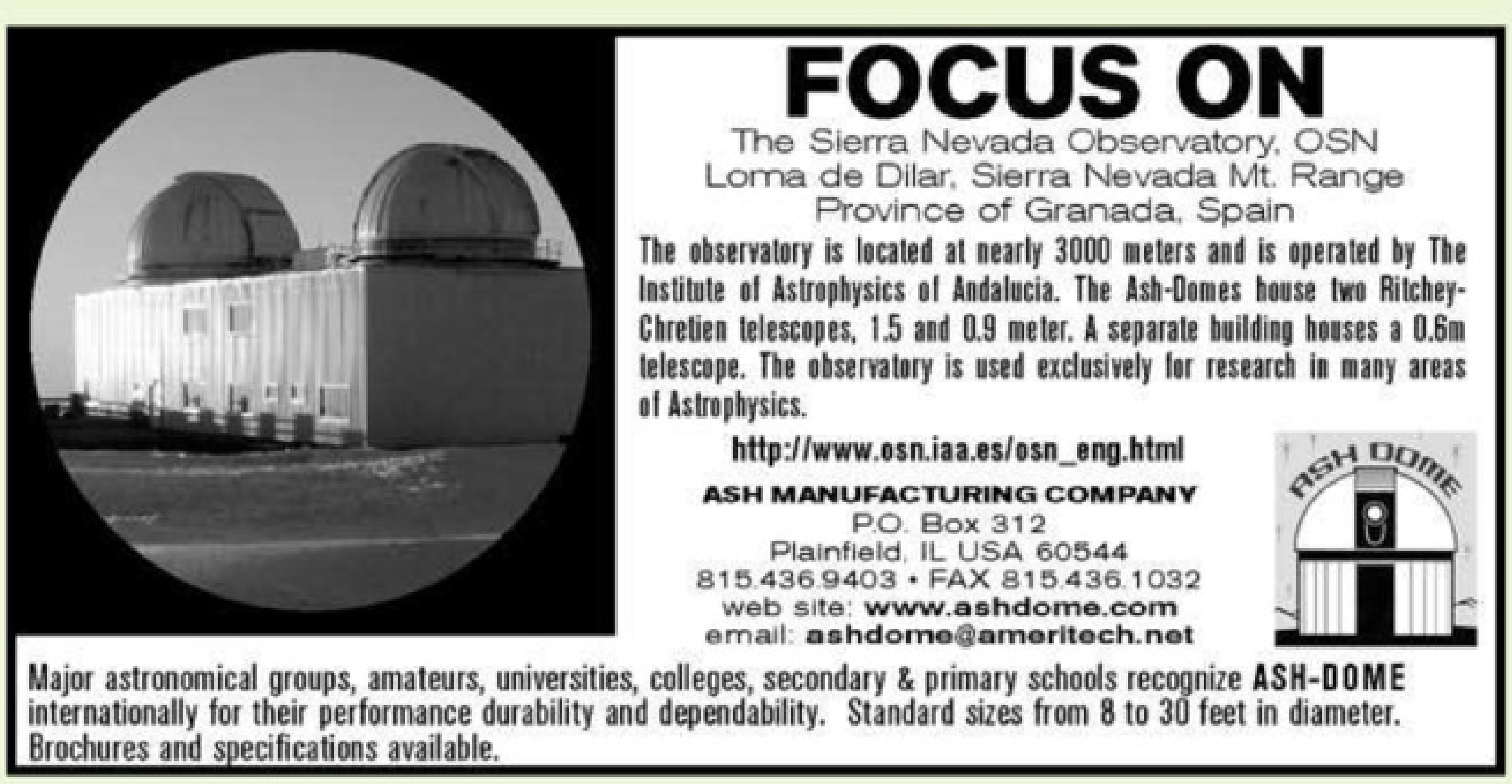
7. SUPER BUBBLE
Henize 70 is expanding because of the stellar winds from massive hot stars in the Large Magellanic Cloud. (20-inch PlaneWave Corrected Dall-Kirkham reflector, Apogee U16M CCD camera, Hα/OIII/SII/RGB image with exposures of 330, 420, 420, 24, 24, and 24 minutes, respectively) • ***Don Goldman***

8. THE WITCH'S BROOM
NGC 6960 in Cygnus wends its way past the star 52 Cygni. The star is a foreground object unconnected to the Veil Nebula supernova remnant, of which the Witch's Broom is a part. (5.6-inch Telescope Engineering Company TEC-140 refractor at f/5.3, FLI MicroLine ML8300 CCD camera, Hα/OIII image with 90 minutes of exposures through each filter) • ***Lynn Hilborn***

9. GALACTIC DUO
NGC 4517 is an edge-on spiral galaxy that floats through Virgo. Above it in this image is the face-on spiral NGC 4517A. Both objects lie 40 million light-years away. (5.6-inch Telescope Engineering Company TEC-140 refractor at f/7, SBIG ST-8300M CCD camera, LRGB image with exposures of 9, 3, 3, and 3 hours, respectively) • ***Bernard Miller***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.





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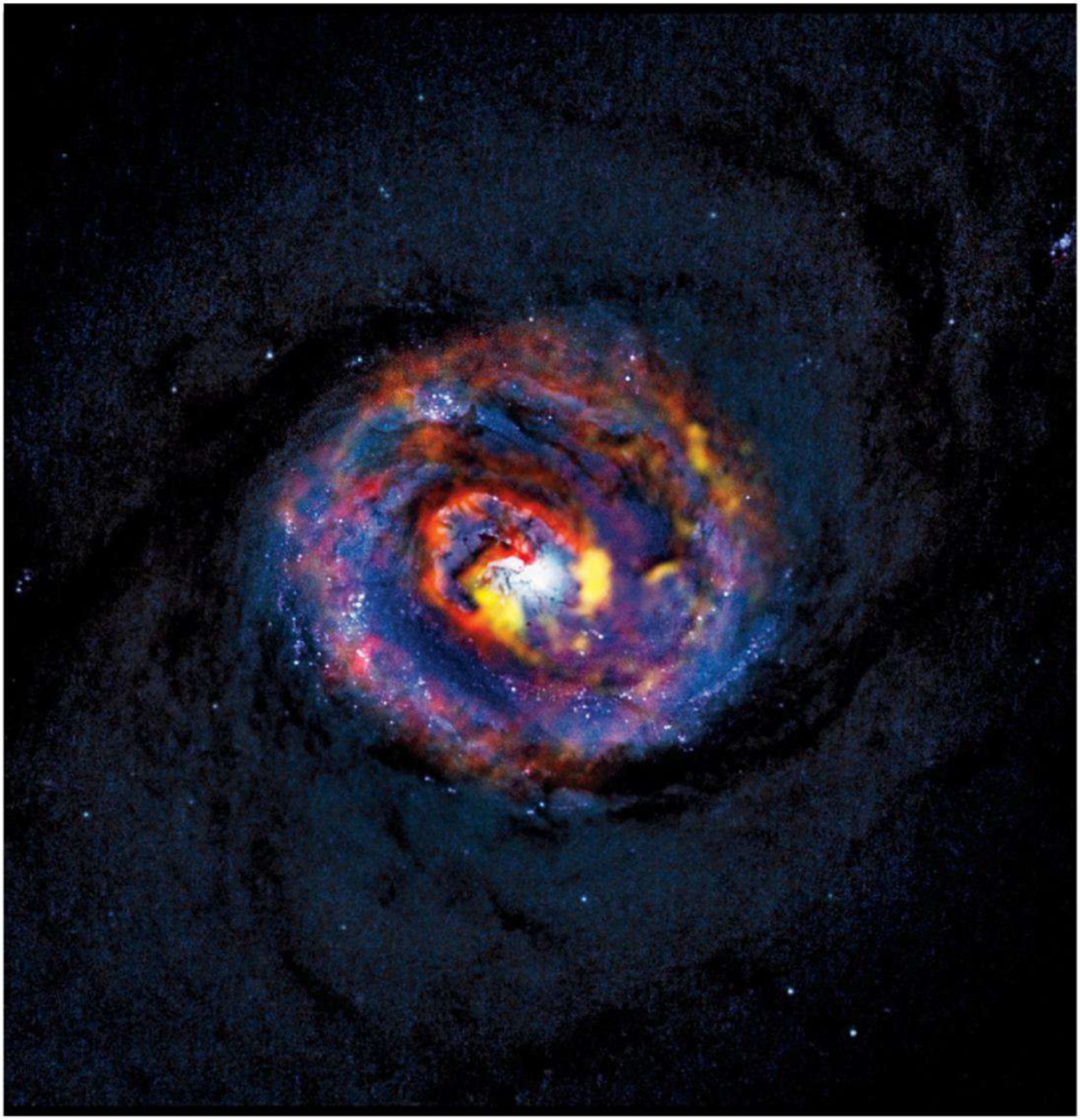

ALMA (ESO/NAOJ/NRAO)/NASA/ESA/F. COMBES

The crazy region around a giant black hole

A new image displays the distortion in a nearby galaxy, NGC 1433, in the southern constellation Horologium. The image, made with the Atacama Large Millimeter/submillimeter Array and the Hubble Space Telescope, shows swirls of material being drawn into the galaxy's black hole or being gravitationally affected by it.

At the same time the astronomers studied the black hole in NGC 1433, they also studied the jet of a distant object known as PKS 1830–211. They compared the distant black hole activity in the PKS galaxy, whose image comes to us from the early universe, with the closer and older black hole activity in NGC 1433. Studying the nearby galaxy allowed astronomers to understand that they had captured PKS 1830–211 in a violent outburst, which will lead to a better understanding of distant black holes.


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Create stunning lunar, solar, and planetary images with Celestron's new USB 3.0 CCD camera: SKYRIS™. We've joined forces with The Imaging Source® to design this cutting-edge camera from the ground up. SKYRIS features fast frame rates and shutter speeds, allowing you to capture planets during brief moments of stable air. Then, using the included iCap and stacking software, you can stack your best images to create vibrant color or monochrome images of Saturn, solar prominences, lunar craters, and so much more. It's available with a variety of popular Sony imaging sensors, so there's a SKYRIS to meet any imager's needs.
// Six models for planteary, lunar, and solar imaging
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// High-speed USB 3.0 connection enables fastest frame rate possible
// 12-bit output provides higher dynamic range
// Heat sink housing minimizes CCD noise
// Includes metal 1.25" nosepiece, 10' USB 3.0 cable, Celestron iCap software, and stacking software.
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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

May 2014: Saturn rules the night

May's evening sky sparkles with good planetary targets. Brilliant **Jupiter** comes into view first after the Sun goes down. Shining at magnitude –1.9 in mid-May, it dominates the backdrop of Gemini the Twins. It appears to the left of that constellation's two brightest stars, Pollux and Castor.

Although the giant planet reached opposition and peak visibility back in January, it remains a nice sight through any telescope. Its disk spans 34" and should show a wealth of detail. Just be sure to view it early in the evening — the planet sets before 9 P.M. local time, and you are more likely to experience moments of steady seeing when it's higher in the sky.

Not long after Jupiter pops out of the darkening sky, **Mars** appears much higher in the northeast. The Red Planet's color contrasts beautifully with the blue-white star Spica directly to its right. Mars lies among the background stars of Virgo, where it treks slowly westward until May 21 before resuming its more typical eastward motion. The planet came to opposition in April and still shines brightly, but you can tell that it's growing dimmer. During the course of May, it fades from magnitude –1.2 to –0.5.

The martian disk also shrinks noticeably this month, from 14.5" to 11.9" across. Fortunately, that's still large enough to show quite a bit of detail through modest-sized telescopes. The most conspicuous feature is the north polar cap, which stands out because it appears bright white and the planet's north pole tilts 25° in our direction. The planet's dusky surface markings take more patience to see.

Jupiter and Mars look really nice, but they still pale in comparison to **Saturn**. The ringed planet reaches opposition May 10, when it remains visible all night and climbs highest in the north around midnight local time. Opposition marks the planet's closest approach to Earth of the year, so it shines brightest (magnitude 0.1) and easily dominates the relatively dim backdrop of Libra the Balance.

As you might guess, Saturn also appears largest when it comes closest to Earth. At opposition, its disk spans 19" and the rings stretch 42" from end to end. Any telescope shows the rings, which tilt 22° to our line of sight. It shouldn't be hard to pick out the nearly black Cassini Division that separates the two brightest ring components. Also watch for Saturn's largest satellite, 8th-magnitude Titan. Tethys, Dione, and Rhea glow at 10th magnitude and show up through 10-centimeter and larger instruments.

Several hours later, **Venus** becomes a prominent object in the eastern sky before sunrise. The brilliant object shines at magnitude –4.0 and appears rather lonely among the faint background stars of Pisces. As Venus draws closer to the Sun, it also moves farther from Earth. The view through a telescope confirms this fact — the planet shrinks from 17" to 14" across while the phase waxes from 67 percent to 77 percent lit.

Mercury becomes an evening object toward the end of May, but this isn't its best appearance of the year. It reaches greatest elongation May 25, when it lies 23° east of the Sun but appears only 3° high in the northwest an hour after sunset. Through a telescope, the planet then spans 8" and appears about one-third lit.

The Full Moon occults Saturn on May 14. People in the South Pacific Ocean, New Zealand, and most of Australia can see the event in a dark sky. From Sydney, Saturn disappears at 10h55m UT and reappears at 11h59m UT.

The starry sky

We have reached the time of year when two of the sky's most prominent constellations appear almost on opposite horizons in the evening sky. After several months of enjoying views of Orion the Hunter, Scorpius the Scorpion reappears low in the southeast at the end of twilight. Its return signals the coming of winter. Experienced Southern Hemisphere stargazers can sometimes feel the cold approaching simply by looking at the sky's most famous arachnid.

The center of Orion lies at a right ascension of around 5h30m while Scorpius comes in close to 17h, so they are roughly opposite each other in the sky. This fits one of the more established stories from Greek mythology. Although there are several variations, they largely boil down to the fact that the sting of a scorpion killed the mythological hunter Orion.

The story goes that Orion had annoyed some people by stating that he would kill every animal on Earth, implying that he was all-powerful and invincible. In one version, Gaia plotted to have a scorpion do away with the hunter so that the creature that ultimately destroyed Orion was far smaller than he was. The two were then sent to the sky and placed far apart.

Many writers claim that the two constellations never appear in the sky at the same time. Although this is true for latitudes well north of the equator, here in the Southern Hemisphere — especially in the temperate zones and farther south — the two certainly appear in the sky at the same time during certain times of the night and year.

The declinations of the two constellations provide an explanation. Orion lies pretty much on the celestial equator, with the main part of his figure appearing between 10° and –10°. The characteristic pattern of Scorpius, on the other hand, ranges between about –15° and –45°. This means that from our part of the world, it remains above the horizon for much longer. From the tip of South America and the Falkland Islands, part of the Scorpion's tail never even sets.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. May 1
8 P.M. May 15
7 P.M. May 31

Planets are shown at midmonth

MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

MAY 2014

Calendar of events

4 The Moon passes 5° south of Jupiter, 14h UT

6 Eta Aquarid meteor shower peaks

The Moon is at apogee (404,318 kilometers from Earth), 10h24m UT

7 First Quarter Moon occurs at 3h15m UT

10 Saturn is at opposition, 18h UT

11 The Moon passes 3° south of Mars, 14h UT

13 Mercury passes 8° north of Aldebaran, 16h UT

14 The Moon passes 0.6° south of Saturn, 12h UT

Full Moon occurs at 19h16m UT

15 Venus passes 1.3° south of Uranus, 13h UT

Asteroid Metis is at opposition, 14h UT

18 The Moon is at perigee (367,102 kilometers from Earth), 11h57m UT

21 Mars is stationary, 9h UT

Last Quarter Moon occurs at 12h59m UT

22 The Moon passes 5° north of Neptune, 4h UT

24 The Moon passes 1.9° north of Uranus, 20h UT

25 Mercury is at greatest eastern elongation (23°), 7h UT

The Moon passes 2° north of Venus, 16h UT

28 New Moon occurs at 18h40m UT

30 The Moon passes 6° south of Mercury, 16h UT

31 Asteroid Eunomia is at opposition, 18h UT